PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF ELECTION

(PCT Rule 61.2)

To:

United States Patent and Trademark
Office
(Box PCT)
Crystal Plaza 2
Washington, DC 20231
ÉTATS-UNIS D'AMÉRIQUE

in its capacity as elected Office

Date of mailing (day/month/year) 04 March 1999 (04.03.99)	
International application No. PCT/IL98/00297	**Applicant's or agent's file reference** 31342
International filing date (day/month/year) 24 June 1998 (24.06.98)	**Priority date** (day/month/year) 24 June 1997 (24.06.97)
Applicant COHEN, Yuval et al	

1. The designated Office is hereby notified of its election made:

   [X] in the demand filed with the International Preliminary Examining Authority on:

   24 January 1999 (24.01.99)

   [ ] in a notice effecting later election filed with the International Bureau on:

2. The election [X] was [ ] was not

   made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO **34, chemin des Colombettes** **1211 Geneva 20, Switzerland** Facsimile No.: (41-22) 740.14.35	Authorized officer Catherine Massetti Telephone No.: (41-22) 338.83.38

EL 128 325 115 US

PATENT COOPERATION TREATY

From the
INTERNATIONAL PRELIMINARY EXAMINING AUTHORITY

To:

WOLFF BREGMAN AND GOLLER
P.O. Box 1352
Jerusalem 91013
ISRAEL

PCT

NOTIFICATION OF TRANSMITTAL OF THE INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Rule 71.1)

Date of mailing (*day/month/year*) 05.10.99

Applicant's or agent's file reference	IMPORTANT NOTIFICATION
-.-	

International application No.	International filing date (*day/month/year*)	Priority date (*day/month/year*)
PCT/IL98/00297	24/06/1998	24/06/1997

Applicant
BE4 LTD. et al.

1. The applicant is hereby notified that this International Preliminary Examining Authority transmits herewith the international preliminary examination report and its annexes, if any, established on the international application.

2. A copy of the report and its annexes, if any, is being transmitted to the International Bureau for communication to all the elected Offices.

3. Where required by any of the elected Offices, the International Bureau will prepare an English translation of the report (but not of any annexes) and will transmit such translation to those Offices.

4. **REMINDER**

   The applicant must enter the national phase before each elected Office by performing certain acts (filing translations and paying national fees) within 30 months from the priority date (or later in some Offices) (Article 39(1)) (see also the reminder sent by the International Bureau with Form PCT/IB/301).

   Where a translation of the international application must be furnished to an elected Office, that translation must contain a translation of any annexes to the international preliminary examination report. It is the applicant's responsibility to prepare and furnish such translation directly to each elected Office concerned.

   For further details on the applicable time limits and requirements of the elected Offices, see Volume II of the PCT Applicant's Guide.

Name and mailing address of the IPEA/	Authorized officer
European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Mader, D Tel.+49 89 2399-2744

Form PCT/IPEA/416 (July 1992)

EL 128325115US

PATENT COOPERATION TREATY

From the:
INTERNATIONAL PRELIMINARY EXAMINING AUTHORITY

To:

WOLFF BREGMAN AND GOLLER
P.O. Box 1352
Jerusalem 91013
ISRAEL

PCT

WRITTEN OPINION

(PCT Rule 66)

Date of mailing (*day/month/year*)	01.07.99

Applicant's or agent's file reference -.-	**REPLY DUE** **within 2 month(s)** from the above date of mailing

International application No.	International filing date (*day/month/year*)	Priority date (*day/month/year*)
PCT/IL98/00297	24/06/1998	24/06/1997

International Patent Classification (IPC) or both national classification and IPC

H04R5/033

Applicant

BE4 LTD. et al.

1. This written opinion is the **first** drawn up by this International Preliminary Examining Authority.
2. This opinion contains indications relating to the following items:
   - I ☒ Basis of the opinion
   - II ☐ Priority
   - III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   - IV ☐ Lack of unity of invention
   - V ☒ Reasoned statement under Rule 66.2(a)(ii) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
   - VI ☐ Certain document cited
   - VII ☒ Certain defects in the international application
   - VIII ☒ Certain observations on the international application
3. The applicant is hereby **invited to reply** to this opinion.

   When? See the time limit indicated above. The applicant may, before the expiration of that time limit, request this Authority to grant an extension, see Rule 66.2(d).

   How? By submitting a written reply, accompanied, where appropriate, by amendments, according to Rule 66.3. For the form and the language of the amendments, see Rules 66.8 and 66.9.

   Also: For an additional opportunity to submit amendments, see Rule 66.4. For the examiner's obligation to consider amendments and/or arguments, see Rule 66.4 bis. For an informal communication with the examiner, see Rule 66.6.

   If no reply is filed, the international preliminary examination report will be established on the basis of this opinion.
4. The final date by which the international preliminary examination report must be established according to Rule 69.2 is: 24/10/1999.

Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. (+49-89) 2399-0 Tx: 523656 epmu d Fax: (+49-89) 2399-4465	Authorized officer / Examiner Draper, A Formalities officer (incl. extension of time limits) Teschauer, B Telephone No. (+49-89) 2399 8231

Form PCT/IPEA/408 (cover sheet) (January 1994)

I. Basis of the opinion

1. This opinion has been drawn on the basis of (*substitute sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this opinion as "originally filed".*):

Description, pages:

1-19 as originally filed

Claims, No.:

1-21 as originally filed

Drawings, sheets:

1/13-13/13 as originally filed

2. The amendments have resulted in the cancellation of:

☐ the description, pages:
☐ the claims, Nos.:
☐ the drawings, sheets:

3. This opinion has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

4. Additional observations, if necessary:

V. Reasoned statement under Rule 66.2(a)(ii) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Claims	1,5,7,8,9,10,11,14,15,17,18,20	No
Inventive step (IS)	Claims	2,4,6,16,19,21	No
Industrial applicability (IA)	Claims		

2. Citations and explanations

see separate sheet

VII. Certain defects in the international application

The following defects in the form or contents of the international application have been noted:

see separate sheet

VIII. Certain observations on the international application

The following observations on the clarity of the claims, description, and drawings or on the question whether the claims are fully supported by the description, are made:

see separate sheet

Section V

1). Citations:
D1...DE-A-26 52 101
D2...FR-A-74 23985
D3...EP-A-0 438 281
D4...DE-A-43 32 504
D5...EP-A-0 705 053

2). Claim 1:
All features of this claim are to be found in D1. See especially D1, Fig. 1 wherein the wireless headphone assembly is shown as items 6-16, the at least one ultrasound receiver is item 6, and the transducer is items 6+9+11+12+14+16
The subject-matter of claim 1 is therefore not novel.
(N.B. the transducer has to be understood as being all these components, as it is stated to be for converting ultrasound to a human audible signal. However, the term "transducer" is evidently used in the later claims to refer either to the ultrasound pickup alone or the loudspeaker alone).

3). Claim 2:
This reads onto an obvious variant of D5. In D5 two I.R. receivers each receive a signal along two I.R. channels (see D5, column 2, line 48 to column 3, line 8). Ultrasound would be an obvious transmission alternative since it has certain advantages over I.R. (cf. D2, page 1, second and third paragraphs).

4). Claim 3:
This could also be considered to be an obvious variation of D5 as modified in the light of D2 to pair up the front left and rear right signals on the one hand and the front right and rear left signals on the other hand. This combination is a choice from among a very few possibilities. It is noted that D5 column 2, line 48 to column 3, line 8 only speaks of combining the two forward channels and the two rearward channels as a preference. The possibility of other combinations is also clearly contemplated. This notwithstanding, if the position of the receivers were properly defined in relation to the wireless headphone assembly (not merely defined as "called a right receiver", "called a left receiver"), and if the essential features

discussed in Section VIII of this written opinion were incorporated, it would seem that the subject-matter of this claim - in combination with claims 1 and 2) would be considered to meet the requirements of Article 33(2) and (3) PCT.

5). Claim 4:
It is obvious, beginning from the arrangement of D1 (see Figs. 1 and 2 thereof), if a four speaker surround headphone, such as that known from D5, is to be rendered cordless, to provide an ultrasound receiver for each channel.

6). Claim 5:
The first and second transducers are to be seen in Fig. 1 of D1 as e.g. the pickup 6 and the loudspeakers 15.

7). Claim 6:
See the reasoning applied to claim 2 above as to why an ultrasound system might be preferred over the I.R. links in D5. The multichannel transducer would be represented by one the receivers receiving on two channels (D5, col. 2, line 56 - col. 3, line 8). Thus an obvious adaptation of the headphones of D5 would lead to an object reading onto the wording of present claim 6.

8). Claim 7:
The bandpass filters are shown as items 8 and 9 in Fig. 1 of D1.

9). Claim 8:
The demodulators are shown as items 10 and 11 in Fig. 1 of D1.

10). Claim 9:
It is clear from D1, page 4, fourth line from the bottom to page 5, line 3 that the transducers 6 and 7 are located adjacent a different ear of the user.

11). Claim 10:
It is presumed that the expression "said at least one second transducer" is in error since there is no precedent for a second transducer in claim 1. In view of the subsequent definition of the function of the second transducers, however, they are taken to be the loudspeakers within the headphones. Such an arrangement,

however, also reads onto D1, the two transducers being visible as 15 and 16 in Fig. 1 thereof.

12). Claim 11:
Similarly there is no precedent in claim 1 for "said at least two ultrasound receivers". This notwithstanding, it is also the case in D1 that an audible signal derived from ultrasound signals received at each of two ultrasound receivers (6,7) is supplied to each ear of a user (via 15,16).

13). Claim 12:
This claim is obscure in speaking of converting <u>ultrasound</u> signals "<u>along</u> at least two <u>human audible</u> channels" (emphasis added by examiner). Nonetheless, this claim is understood to relate to essentially a generalisation of the crossover from left receiver to right rear audio transducer and right receiver to left rear audio transducer as defined in claim 3. See remarks concerning claim 3 above and the remarks concerning essential features in Section VIII of this written opinion.

14). Claim 13:
This claim is dependent on claim 12 and thus relates to an advantageous embodiment of the subject-matter of that claim.

15). Claim 14:
This claim is unclear because it suggests that the headphone need only receive one channel and convert it to audible form (cf. "at least one ultrasound converter", "at least one ultrasound signal", "at least one ultrasound channel", "at least one transducer") whereas the transmitter transmits along a plurality of channels. This would not serve the purpose intended.
However, even understanding that the headphone assembly should receive a plurality of channels, the subject-matter of this claim reads onto D1 if one takes the combination of modulators 19 and 20 in Fig. 2 thereof (showing the situation for the stereo variant) to be the "at least one processor".

16). Claim 15:
This also reads onto D1. The whole point of D1 is to produce the effect described in claim 15.

17). Claim 16:
This claim not only suffers from the same deficiencies in respect of essential features as claims 3 and 12, it even lacks the feature that the receivers are ultrasound receivers. Its subject-matter is considered to read onto an obvious variant of D5 (not even modified in the light of D2) as discussed in relation to claim 3 above.

18). Claim 17:
The subject-matter of this claim is entirely preempted by D1 - see esp. Fig. 1.

19). Claim 18:
This is anticipated by D3. In D3, Fig. 1 the headphone assembly is reference 10, the ultrasound reference is sent by 11, the processing of arrival times is performed in 14, the modulation (in phase) is performed in 21 and the sending of the at least two audio signals is performed between 22 and 23.

20). Claim 19:
That the ultrasound reference is sent by ultrasound carrier in D3 is self-evident. Sending also the audio signals by an ultrasound carrier is not inventive in light of e.g. D1 or D2.

21). Claim 20:
Given no indication to the contrary, the skilled person would implicitly understand that the circuit lines between features 22 and 23 represent wires. The subject-matter of claim 20 thus reads directly onto D3.

22). Claim 21:
On the other hand, sending the audio signals wirelessly is an obvious alternative in light of e.g. D1, D2, or D3.

<u>Section VII</u>

1). In accordance with the requirements of Rule 5.1(a)(ii) PCT, the relevant background art disclosed in the documents D1, D3 and D5 should be mentioned

and briefly discussed in the description.

2). The independent claims are not in the two-part form in accordance with Rule 6.3(b) PCT, which in the present case would be appropriate, with those features known in combination from the closest prior art (document D1) being placed in a preamble (Rule 6.3(b)(i) PCT) and with the remaining features being included in a characterising part (Rule 6.3(b)(ii) PCT - see also the PCT Guidelines PCT/GL/3 III, 2.3a).

3). The features of the claims are not provided with reference signs placed in parentheses (Rule 6.2(b) PCT).

4). If filing new claims the description should be adapted to their scope.

<u>Section VIII</u>

1). For the headphones to serve the purpose of providing surround sound, firstly, there must be (at least) two ultrasound receivers (microphones) and loudspeakers (one for each ear), secondly, the microphones must be physically located one near to each ear of the user (cf. description, page 14, lines 12-14), thirdly, a crossover of the rear channels must be accompanied by a delay in the rear channels (see especially page 14, line 18 - page 16, line 2). These are thus considered to be essential features within the meaning of PCT Guidelines, PCT/GL/3 III, 4.4 and to belong in any independent claim. Lack of these features is considered to render the claims unclear (Article 6 PCT).

2). Claims 10, 11, 12 and 14 contain unclarities. See remarks concerning those respective claims in Section V of this written opinion.

3). The plurality of independent claims of overlapping scope in each category (apparatus, method) renders them inconcise as a whole (Article 6 PCT).

4). The statement in the description on page 19, last paragraph implies that the subject-matter for which protection is sought may be different to that defined by the claims, thereby resulting in lack of clarity (Article 6 PCT) when used to in-

terpret them (see also the PCT Guidelines, PCT/GL/3 III, 4.3a).

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FAX +49 89 2399-4465

Correspondence with the EPO on PCT Chapter II demands

In order to ensure that your PCT Chapter II demand is dealt with as promptly as possible you are requested to use the enclosed self-adhesive labels with any correspondence relating to the demand sent to the Munich Office.

One of these labels should be affixed to a prominent place in the upper part of the letter or form etc. which you are filing.

PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference	FOR FURTHER ACTION	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
-.-		
International application No. PCT/IL98/00297	International filing date *(day/month/year)* 24/06/1998	Priority date *(day/month/year)* 24/06/1997
International Patent Classification (IPC) or national classification and IPC H04R5/033		
Applicant BE4 LTD. et al.		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 8 sheets, including this cover sheet.

   ☐ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of sheets.

3. This report contains indications relating to the following items:

   - I ☒ Basis of the report
   - II ☐ Priority
   - III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   - IV ☐ Lack of unity of invention
   - V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations suporting such statement
   - VI ☐ Certain documents cited
   - VII ☒ Certain defects in the international application
   - VIII ☒ Certain observations on the international application

Date of submission of the demand	Date of completion of this report
24/01/1999	05.10.99
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized officer Draper, A Telephone No. +49 89 2399 8947

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No. PCT/IL98/00297

I. Basis of the report

1. This report has been drawn on the basis of (*substitute sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to the report since they do not contain amendments.*):

Description, pages:

1-19 as originally filed

Claims, No.:

1-21 as originally filed

Drawings, sheets:

1/13-13/13 as originally filed

2. The amendments have resulted in the cancellation of:

- ☐ the description, pages:
- ☐ the claims, Nos.:
- ☐ the drawings, sheets:

3. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

4. Additional observations, if necessary:

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No. PCT/IL98/00297

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	2-4,6,12,13,16,19,21
	No:	Claims	1,5,7,8,9,10,11,14,15,17,18,20
Inventive step (IS)	Yes:	Claims	3,12,13
	No:	Claims	2,4,6,16,19,21
Industrial applicability (IA)	Yes:	Claims	1-21
	No:	Claims	

2. Citations and explanations

see separate sheet

VII. Certain defects in the international application

The following defects in the form or contents of the international application have been noted:

see separate sheet

VIII. Certain observations on the international application

The following observations on the clarity of the claims, description, and drawings or on the question whether the claims are fully supported by the description, are made:

see separate sheet

Section V

1). Citations:
D1...DE-A-26 52 101
D2...FR-A-74 23985
D3...EP-A-0 438 281
D4...DE-A-43 32 504
D5...EP-A-0 705 053

2). Claim 1:
All features of this claim are to be found in D1. See especially D1, Fig. 1 wherein the wireless headphone assembly is shown as items 6-16, the at least one ultrasound receiver is item 6, and the transducer is items 6+9+11+12+14+16
The subject-matter of claim 1 is therefore not novel.
(N.B. the transducer has to be understood as being all these components, as it is stated to be for converting ultrasound to a human audible signal. However, the term "transducer" is evidently used in the later claims to refer either to the ultrasound pickup alone or the loudspeaker alone).

3). Claim 2:
This reads onto an obvious variant of D5. In D5 two I.R. receivers each receive a signal along two I.R. channels (see D5, column 2, line 48 to column 3, line 8). Ultrasound would be an obvious transmission alternative since it has certain advantages over I.R. (cf. D2, page 1, second and third paragraphs).

4). Claim 3:
This could also be considered to be an obvious variation of D5 as modified in the light of D2 to pair up the front left and rear right signals on the one hand and the front right and rear left signals on the other hand. This combination is a choice from among a very few possibilities. It is noted that D5 column 2, line 48 to column 3, line 8 only speaks of combining the two forward channels and the two rearward channels as a preference. The possibility of other combinations is also clearly contemplated. This notwithstanding, if the position of the receivers were properly defined in relation to the wireless headphone assembly (not merely defined as "called a right receiver", "called a left receiver"), and if the essential features

discussed in Section VIII of this written opinion were incorporated, it would seem that the subject-matter of this claim - in combination with claims 1 and 2) would be considered to meet the requirements of Article 33(2) and (3) PCT.

5). Claim 4:
It is obvious, beginning from the arrangement of D1 (see Figs. 1 and 2 thereof), if a four speaker surround headphone, such as that known from D5, is to be rendered cordless, to provide an ultrasound receiver for each channel.

6). Claim 5:
The first and second transducers are to be seen in Fig. 1 of D1 as e.g. the pickup 6 and the loudspeakers 15.

7). Claim 6:
See the reasoning applied to claim 2 above as to why an ultrasound system might be preferred over the I.R. links in D5. The multichannel transducer would be represented by one the receivers receiving on two channels (D5, col. 2, line 56 - col. 3, line 8). Thus an obvious adaptation of the headphones of D5 would lead to an object reading onto the wording of present claim 6.

8). Claim 7:
The bandpass filters are shown as items 8 and 9 in Fig. 1 of D1.

9). Claim 8:
The demodulators are shown as items 10 and 11 in Fig. 1 of D1.

10). Claim 9:
It is clear from D1, page 4, fourth line from the bottom to page 5, line 3 that the transducers 6 and 7 are located adjacent a different ear of the user.

11). Claim 10:
It is presumed that the expression "said at least one second transducer" is in error since there is no precedent for a second transducer in claim 1. In view of the subsequent definition of the function of the second transducers, however, they are taken to be the loudspeakers within the headphones. Such an arrangement,

however, also reads onto D1, the two transducers being visible as 15 and 16 in Fig. 1 thereof.

12). Claim 11:
Similarly there is no precedent in claim 1 for "said at least two ultrasound receivers". This notwithstanding, it is also the case in D1 that an audible signal derived from ultrasound signals received at each of two ultrasound receivers (6,7) is supplied to each ear of a user (via 15,16).

13). Claim 12:
This claim is obscure in speaking of converting <u>ultrasound</u> signals "<u>along</u> at least two <u>human audible</u> channels" (emphasis added by examiner). Nonetheless, this claim is understood to relate to essentially a generalisation of the crossover from left receiver to right rear audio transducer and right receiver to left rear audio transducer as defined in claim 3. See remarks concerning claim 3 above and the remarks concerning essential features in Section VIII of this IPER.

14). Claim 13:
This claim is dependent on claim 12 and thus relates to an advantageous embodiment of the subject-matter of that claim.

15). Claim 14:
This claim is unclear because it suggests that the headphone need only receive one channel and convert it to audible form (cf. "at least one ultrasound converter", "at least one ultrasound signal", "at least one ultrasound channel", "at least one transducer") whereas the transmitter transmits along a plurality of channels. This would not serve the purpose intended.
However, even understanding that the headphone assembly should receive a plurality of channels, the subject-matter of this claim reads onto D1 if one takes the combination of modulators 19 and 20 in Fig. 2 thereof (showing the situation for the stereo variant) to be the "at least one processor".

16). Claim 15:
This also reads onto D1. The whole point of D1 is to produce the effect described in claim 15.

17). Claim 16:
This claim not only suffers from the same deficiencies in respect of essential features as claims 3 and 12, it even lacks the feature that the receivers are ultrasound receivers. Its subject-matter is considered to read onto an obvious variant of D5 (not even modified in the light of D2) as discussed in relation to claim 3 above.

18). Claim 17:
The subject-matter of this claim is entirely preempted by D1 - see esp. Fig. 1.

19). Claim 18:
This is anticipated by D3. In D3, Fig. 1 the headphone assembly is reference 10, the ultrasound reference is sent by 11, the processing of arrival times is performed in 14, the modulation (in phase) is performed in 21 and the sending of the at least two audio signals is performed between 22 and 23.

20). Claim 19:
That the ultrasound reference is sent by ultrasound carrier in D3 is self-evident. Sending also the audio signals by an ultrasound carrier is not inventive in light of e.g. D1 or D2.

21). Claim 20:
Given no indication to the contrary, the skilled person would implicitly understand that the circuit lines between features 22 and 23 represent wires. The subject-matter of claim 20 thus reads directly onto D3.

22). Claim 21:
On the other hand, sending the audio signals wirelessly is an obvious alternative in light of e.g. D1, D2, or D3.

Section VII

1). The relevant background art disclosed in the documents D1, D3 and D5 has not been mentioned and briefly discussed in the description (Rule 5.1(a)(ii) PCT).

2). The independent claims are not in the two-part form in accordance with Rule 6.3(b) PCT, which in the present case would be appropriate, with those features known in combination from the closest prior art (document D1) being placed in a preamble (Rule 6.3(b)(i) PCT) and with the remaining features being included in a characterising part (Rule 6.3(b)(ii) PCT - see also the PCT Guidelines PCT/GL/3 III, 2.3a).

3). The features of the claims are not provided with reference signs placed in parentheses (Rule 6.2(b) PCT).

Section VIII

1). For the headphones to serve the purpose of providing surround sound, firstly, there must be (at least) two ultrasound receivers (microphones) and loudspeakers (one for each ear), secondly, the microphones must be physically located one near to each ear of the user (cf. description, page 14, lines 12-14), thirdly, a crossover of the rear channels must be accompanied by a delay in the rear channels (see especially page 14, line 18 - page 16, line 2). These are thus considered to be essential features within the meaning of PCT Guidelines, PCT/GL/3 III, 4.4 and to belong in any independent claim. Lack of these features is considered to render the claims unclear (Article 6 PCT).

2). Claims 10, 11, 12 and 14 contain unclarities. See remarks concerning those respective claims in Section V of this written opinion.

3). The plurality of independent claims of overlapping scope in each category (apparatus, method) renders them inconcise as a whole (Article 6 PCT).

4). The statement in the description on page 19, last paragraph implies that the subject-matter for which protection is sought may be different to that defined by the claims, thereby resulting in lack of clarity (Article 6 PCT) when used to interpret them (see also the PCT Guidelines, PCT/GL/3 III, 4.3a).

PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference 31342	**FOR FURTHER ACTION** see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.	
International application No. PCT/IL 98/00297	International filing date *(day/month/year)* 24/06/1998	(Earliest) Priority Date *(day/month/year)* 24/06/1997
Applicant BE4 LTD. et al.		

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 3 sheets.

[X] It is also accompanied by a copy of each prior art document cited in this report.

1. [ ] **Certain claims were found unsearchable** (see Box I).

2. [ ] **Unity of invention is lacking** (see Box II).

3. [ ] The international application contains disclosure of a **nucleotide and/or amino acid sequence listing** and the international search was carried out on the basis of the sequence listing
   - [ ] filed with the international application.
   - [ ] furnished by the applicant separately from the international application,
     - [ ] but not accompanied by a statement to the effect that it did not include matter going beyond the disclosure in the international application as filed.
   - [ ] Transcribed by this Authority

4. With regard to the **title**,
   - [X] the text is approved as submitted by the applicant
   - [ ] the text has been established by this Authority to read as follows:

5. With regard to the **abstract**,
   - [X] the text is approved as submitted by the applicant
   - [ ] the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this International Search Report, submit comments to this Authority.

6. The figure of the **drawings** to be published with the abstract is:

   Figure No. 5
   - [ ] as suggested by the applicant.
   - [ ] because the applicant failed to suggest a figure.
   - [X] because this figure better characterizes the invention.
   - [ ] None of the figures.

INTERNATIONAL SEARCH REPORT

International Application No
PCT/IL 98/00297

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H04R5/033

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H04R H04S H04B G06K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 26 52 101 A (LICENTIA PATENT) 18 May 1978	1,2,5,8, 9,17
Y	see page 3, line 21 - page 4, line 20	3,6, 10-12, 14-16, 18,19,21
A	see page 4, line 29 - page 6, line 19	4,20

X	FR 2 237 386 A (PHILIPS) 7 February 1975	1,5,8,9, 17
Y	see page 1, line 1-29	6,10, 14-16, 18,19,21
A	see page 2, line 24 - page 6, line 12	2-4,11, 12,20

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
9 December 1998	17/12/1998

Name and mailing address of the ISA	Authorized officer
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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 438 281 A (SONY) 24 July 1991	16,18,20
A	see column 2, line 39 - column 3, line 56	1-3,6,9, 12,13, 19,21
	see column 4, line 16 - column 9, line 42	

Y	DE 43 32 504 A (F. KÖNIG) 30 March 1995	3,6, 10-12,16
A	see column 1, line 3-11	1,7,13
	see column 2, line 52 - column 5, line 31	

Y	EP 0 705 053 A (MARIKON RESOURCES) 3 April 1996 see column 2, line 2 - column 3, line 25	3,6, 10-12,16

Y	EP 0 100 153 A (STEREO CONCEPTS) 8 February 1984 see page 1, line 3-12 see page 10, line 11 - page 17, line 9	14,15, 18,19,21

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 :
H04S 1/00

A2

(11) International Publication Number: WO 98/59525

(43) International Publication Date: 30 December 1998 (30.12.98)

(21) International Application Number: PCT/IL98/00297

(22) International Filing Date: 24 June 1998 (24.06.98)

(30) Priority Data:
121155 24 June 1997 (24.06.97) IL

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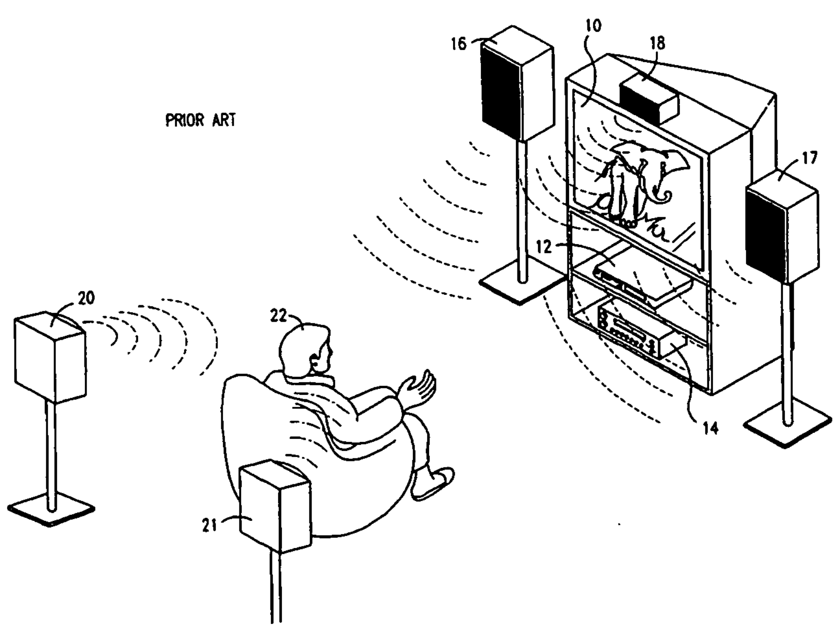
(81) Designated States: AL, AM, AT, AT (Utility model), AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, CZ (Utility model), DE, DE (Utility model), DK, DK (Utility model), EE, EE (Utility model), ES, FI, FI (Utility model), GB, GE, GH, GM, GW, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SK (Utility model), SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

Published
Without international search report and to be republished upon receipt of that report.

(54) Title: SYSTEM FOR PRODUCING AN ARTIFICIAL SOUND ENVIRONMENT



(57) Abstract

A method for simulating an artificial sound environment including sending an ultrasound reference signal to a headphone assembly worn by a user having two ears, the headphone assembly audibly providing at least one audio signal to each of the ears, processing arrival times of the ultrasound reference signal at each ear, so as to measure a phase difference of the signal as perceived by one ear in contrast to the other ear, modulating at least two audio signals, at least one signal for each ear, in accordance with the phase difference, and sending the at least two audio signals via the headphone assembly to each of the ears.

SYSTEM FOR PRODUCING AN ARTIFICIAL SOUND ENVIRONMENT

FIELD OF THE INVENTION

The present invention relates to the field of headphones for the provision of surround sound in audio reproduction systems.

BACKGROUND OF THE INVENTION

The capabilities of the simple Hi-Fi stereo system have been extended recently to incorporate the surround sound effects required by home theater systems. Such systems include a large-screen television receiver or video cassette player, four additional speakers, and a surround amplifier. The new system dramatically improves the immersion of the viewer in the sound effects of the movie.

A typical home theater system combines video capabilities with advanced audio systems, and it is based on the following major components:

1. A large screen TV receiver or video projector.
2. A laser disk player or a Hi-Fi video cassette player, which is the source of the audio and video signals. The audio track recorded on the film is not an ordinary stereo track. It encrypts additional information about the sound channels. The encryption protocols have evolved over the years. There are three major standards currently in use:
    a. Dolby ProLogic Surround, in which in addition to the standard left and right channels, a center channel and a rear channel are recorded on the sound track. All channels are analog.
    b. THX, manufactured by the Lucas film company, in which two separate rear channels are used instead of one. All channels are analog.
    c. AC-3, the latest development by Dolby lab, in which six channels of music are digitally recorded on the sound track - front right, front left, center, rear right, rear left and subwoofer. The latter is not a full spectrum channel, as only one octave is necessary.
3. A surround amplifier, for extracting the surround channels from the incoming signal. Surround amplifiers are typically based on the Dolby chip. Most amplifiers have DSP (Digital Signal Processor) capabilities, which can modify the sound of a non-surround music source to sound as if it originates from different artificial acoustic environments, such as a concert hall, a theater, a jazz club, etc.

4. Speakers. A full surround system requires six different speakers, which must be of high quality to ensure realistic reproduction. Their function is as follows:

a. Two main speakers, which reproduce most of the sound and music effect.

b. One center speaker, located above or below the screen. This speaker is dedicated to the actors' voices.

c. Two rear speakers, responsible for the special effects generated by the surround sound system, and for the artificial echo effects generated in the different DSP modes of the surround amplifier.

d. A subwoofer, for reproducing all low frequency sounds, such as explosions. Location of the subwoofer is not critical, as this channel contains little directional information. Furthermore, such low frequency sound waves are felt by many parts of the body, and not specifically by the ears. The subwoofer is usually placed in the front field.

The room itself has to be modified to fit the home theater requirements:

a. Since there are six different sound sources in the room, any unwanted echo destroys the sound quality and directionality. The room must therefore be covered with acoustically absorbing materials, such as carpets and drapes.

b. Acoustical isolating materials must be used to avoid disturbing neighbors.

c. Wiring to the various speakers must be installed in the room, preferably without being a visual eyesore.

Each of the system elements affects the overall sound quality. The most important factor is the room acoustics. If the room is big and the walls bare, the echo severely affects the sound. The quality of the speakers is also a major element of the system. High performance speakers are large and expensive, but essential for good sound. Finally, the high power, low distortion amplifiers required for realistic surround sound are expensive.

These requirements make high quality surround sound systems very expensive both to purchase and to install in the home.

In order to provide high quality audio reproduction at low cost and at a personal level of listening, conventional Hi Fi audio systems have for a long time made use of stereo headphones. Attempts to utilize headphones to provide surround sound have been made by a number of manufacturers with limited success. In order to appreciate the problems involved in achieving an effective implementation of surround sound headphone technology, it is

necessary to understand the physiological effects used by humans in experiencing three dimensional hearing.

In order to recognize the direction of a sound, the brain combines information received by the two ears and uses several psycho-acoustic effects to achieve a 3-D sensation of the surrounding world, as follows:

1. Phase difference: The sound does not reach both ears in the same phase - the ear closer to the sound source hears the sound first. By calculating the minute differences in time of arrival of the sound at the two ears (<1 msec.), the brain can detect the origin of the sound.
2. Level difference: The ear closer to the sound source hears a louder sound. This information is converted by the brain into directional and range information.
3. Head rotation: If, for example, the sound source is directly in front of or directly behind the listener, the phase and level difference between the two ears is zero. The body executes small, almost unnoticeable head movements in order to identify the origin of a sound. Even the smallest movement creates phase differences significant enough for the brain to discern the orientation of the source.
4. Doppler pitch difference: During head rotation, the sound pitch changes due to the Doppler effect. The ear which rotates towards the source hears a slightly higher pitch than the other one. The brain is capable of detecting this slight change in pitch, and decoding the source direction from this information.
5. Face blockage: While rotating the head away from the sound source, at a certain angle, the listener's head causes one ear to move into the "acoustical shade area" from the sound source, and the sound level in this ear becomes lower than in the other one. The brain uses this effect to locate the sound origin point.

The first three effects are the most important, but in order to get a perfect illusion, all five have to be reproduced correctly. When surround sound is produced by an array of speakers, the sound field produced is very similar to that present in real life, and the human brain is able to make use of all five of the above effects to appreciate the sound.

The use of headphones, however, effectively eliminates all five of the above effects present in free space propagation, since the sound originates from highly localized transducers close to the listener's ears. As the listener moves or turns his head, the headphones move together with the listener's head. The use of simple binaural audio signals

do not therefore give a perception of realism, since the sound field moves with the listener's head. In order to create a true surround sound effect, the audio signal supplied to the headphones must be coded in a sophisticated manner in order to simulate all five of the above psycho-acoustic effects as the listener moves while listening to the performance or the film.

Japanese Unexamined Patent Publication No. Sho 42-227 and Japanese Examined Patent Publication No. 54-19242 describe a surround sound headphone system including a gyro compass or a magnetic needle compass installed on the headphones to measure head movement and to transmit information about head position to a microprocessor. This microprocessor modifies the sound track signal according to the head angle, and transmits the modified signal back to the headphones, so that the listener experiences a surround sound effect. Such a system, using a gyroscope mounted in the headphones, has been marketed by the Sony Corporation. In USA Patent Nos. 5,181,248, 5,452,359 and 5,495,534, a further development of this system is described in which the gyroscope is replaced by an ultrasonic ranging system. The angular location of the head is obtained from relative time-of-arrival measurements of an ultrasonic reference signal emitted by a transmitter located in front of the listener, by means of ultrasonic detectors located in the left and right arms of the headphone set. As previously, a microprocessor modifies the sound track signal according to the measured head angle, and transmits the modified signal back to the headphones, so that the listener experiences a surround sound effect.

In a further system, developed by Virtual Listening Systems Inc. and described in Stereo Review, April 97, p. 38, head movements are ignored completely. The surround sound effects from typical audio situations are pre-programmed by algorithms which provide the phase shifts and volume changes corresponding to various situations. This system therefore simulates the surround sound effect by digital processing means.

All of the above-mentioned prior art systems use advanced real-time signal processing to modify the audio signal information. But the speed of available processors is such that they are unable to process the signals effectively, and the subjective results are unsatisfactory for a number of reasons:

a. The systems deal only with the main psycho-acoustic parameters affecting 3-D recognition, namely the first two, or at best three, in the list above. They all ignore the other usually neglected, yet important effects of Doppler pitch change effect and face blockage.

b. The relatively slow signal sampling rate results in an unnatural "metallic sound".

c. The currently available real time computing used is not fast enough. If the listener turns his head too fast, the computing delay is clearly discerned and disturbing.

d. In both the above mentioned commercially marketed systems, RF is used for communication between the headphones and the processor. RF is prone to interference from external sources such as cellular phones, radio transmitters or even a second headphone system nearby. Conversely, RF can interfere with other such systems.

e. The processor can only deal with one set of headphones. In order for a second listener to enjoy the movie, a complete second system needs to be purchased.

f. Because of the complexity of the systems, they are expensive.

Therefore, it would be desirable to provide a headphone surround sound system which overcomes the disadvantages of the prior art technology, in that:

a. It takes into consideration all five physiological aspects of 3-D sound appreciation, to provide perfect surround illusion;

b. It provides excellent sound quality, without any hesitation or metallic-sounding effects;

c. It is useable by several listeners, each listener requiring only a separate pair of headphones, all being controlled by one processing unit;

d. It is reasonably priced, and

e. It does not use interference-prone RF communication channels.

SUMMARY OF THE INVENTION

The present invention seeks to provide an improved headphone surround sound system.

There is thus provided in accordance with a preferred embodiment of the present invention a set of headphones, having earpieces each of which is equipped with an ultrasound detector for picking up the modulated audio signal information on an ultrasound wave transmitted into the listening area from an ultrasound transmitter, above-mentioned information being derived from the processing and modulating of an audio signal, so as to simulate the effects of surround sound. The processing and modulating of the audio signal is executed by an array of delay lines and modulators, connected and constructed such as to code the audio signal inputted to the earpieces with a simulation of the physiological effects that would be felt when listening to the audio signal propagated in free space.

It is noted that throughout the specification and claims, the term "headphone" encompasses not only headphones, but also any other apparatus for listening via the ears, such as a virtual reality helmet, for example.

There is also provided in accordance with another preferred embodiment of the present invention, a wireless headphone assembly including at least one ultrasound receiver for receiving at least one ultrasound signal along at least one ultrasound channel, and at least one transducer for converting each of the at least one ultrasound signal along the at least one ultrasound channel to a human audible signal.

Additionally, there is provided in accordance with yet another preferred embodiment of the present invention, a wireless headphone assembly wherein said at least one ultrasound receiver includes two ultrasound receivers, each of which receives an ultrasound signal along two ultrasound channels.

There is further provided in accordance with still another preferred embodiment of the present invention, a wireless headphone assembly wherein the at least one ultrasound receiver includes four ultrasound receivers, each of which receives an ultrasound signal along one ultrasound channel.

There is also provided in accordance with yet another preferred embodiment of the present invention, a wireless headphone assembly and wherein the at least one transducer includes at least one first transducer which converts the at least one ultrasound signal to at least one modulated electrical signal and at least one second transducer which converts the at least one modulated electrical signal to a human audible signal.

In addition, there is provided in accordance with another preferred embodiment of the present invention, a wireless headphone assembly and wherein at least one transducer comprises at least one multichannel transducer.

There is also provided in accordance with yet another preferred embodiment of the present invention, a wireless headphone assembly including at least one band pass filter associated with each ultrasound channel.

There is further provided in accordance with still another preferred embodiment of the present invention, a wireless headphone assembly including at least one demodulator associated with each ultrasound channel.

In addition, there is provided in accordance with a further preferred embodiment of the present invention, a wireless headphone assembly and wherein the at least one first transducer operative to convert the at least one ultrasound signal to at least one modulated electrical

signal, includes at least two first transducers, each arranged to be located adjacent to a different ear of a user.

There is further provided in accordance with yet another preferred embodiment of the present invention, a wireless headphone assembly wherein the at least one second transducer includes at least two transducers, each providing a human audible output to a different ear of a user.

In addition, there is provided in accordance with another preferred embodiment of the present invention, a wireless headphone assembly wherein a human audible signal derived from ultrasound signals received at each of the at least two ultrasound receivers is supplied to each ear of a user.

There is also provided in accordance with yet another preferred embodiment of the present invention, a wireless headphone assembly and wherein the at least two ultrasound receivers each receive ultrasound signals along at least two ultrasonic channels, the at least two transducers convert ultrasound signals along at least two human audible channels to human audible signals, and information received along each one of the at least two channels of each of the at least two ultrasound receivers is supplied to each of two different ears of the user along a separate one of the human audible channels.

There is further provided in accordance with still another preferred embodiment of the present invention, a wireless headphone assembly including delay lines operative to simulate the acoustic delay occurring between the arrival of sound from at least one signal source at different ears of the user.

In addition, there is provided in accordance with yet another preferred embodiment of the present invention, a headphone system providing a simulated multi-source sound environment including at least one wireless headphone assembly which may be worn by a user and which includes at least one ultrasound receiver for receiving at least one ultrasound signal along at least one ultrasound channel and at least one transducer for converting each of the at least one ultrasound signal along the at least one ultrasound channel to a human audible signal, and at least one processor receiving a multi-source signal and modulating the sound carrier along the plurality of channels in accordance with the multi-source signal, and at least one transmitter for transmitting the modulated sound carrier to the pair of headphones along a plurality of channels.

In addition, there is provided in accordance with yet another preferred embodiment of the present invention, a headphone system wherein the use of ultrasound for transmitting the

modulated carrier to the at least one headphone is operative to cause a listener using the headphone to experience the psycho-acoustic effects that he would experience if the multi source signals were transmitted in free space as audible sound waves from suitably located sound sources.

There is further provided in accordance with yet another preferred embodiment of the present invention, a method for simulating an artificial sound environment including converting an audible signal to an ultrasound wave, receiving the ultrasound wave by means of a wireless headphone assembly, and converting the ultrasound wave to an audible signal by means of the wireless headphone assembly.

There is also provided in accordance with a preferred embodiment of the present invention a method for simulating an artificial sound environment including sending an ultrasound reference signal to a headphone assembly worn by a user having two ears, the headphone assembly audibly providing at least one audio signal to each of the ears, processing arrival times of the ultrasound reference signal at each the ear, so as to measure a phase difference of the signal as perceived by one the ear in contrast to the other ear, modulating at least two audio signals, at least one signal for each the ear, in accordance with the phase difference, and sending the at least two audio signals via the headphone assembly to each of the ears.

In accordance with a preferred embodiment of the present invention the method also includes sending the at least two audio signals and the ultrasound reference signal via an ultrasound carrier.

Further in accordance with a preferred embodiment of the present invention the step of sending the at least two audio signals includes sending the signals to the headphone assembly by wired communication.

Still further in accordance with a preferred embodiment of the present invention the step of sending the at least two audio signals includes sending the signals to the headphone assembly by wireless communication.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be understood and appreciated more fully from the following detailed description, taken in conjunction with the drawings in which:

Fig. 1 is a pictorial representation of a prior art conventional speaker-based surround sound system, showing the component parts and their mutual location;

Figs. 2A and 2B illustrate how, in the prior art conventional speaker-based surround sound system, the listener detects the direction from which a sound emanates by discerning the small time difference between receipt of the sound by the ear closer to the origin, and by that further from the origin;

Figs. 3A and 3B show how, in the prior art conventional speaker-based surround sound system, the listener detects the direction from which a sound emanates, and by rotating his head towards the sound origin, equalizes the phase of the sound heard by both ears;

Fig. 4A and Fig. 4B present the timing sequence of the receipt of the sound by the left and right ears of a listener seated in front of a conventional prior art surround sound system, and how the timing sequence changes when he rotates his head towards the sound origin and equalizes the phase of the sound heard by both ears;

Fig. 5 is a pictorial representation of a headphone-based surround sound system constructed and operative in accordance with a preferred embodiment of the present invention;

Fig. 6 is a block diagram of an encoder unit constructed and connected in accordance with a preferred embodiment of the present invention, showing how the five separate inputs from the surround sound audio signals are inputted through delay lines and modulators to provide the correct mixture of signals for outputting to the ultrasound transmitter;

Fig. 7 is a schematic block diagram of a pair of headphones constructed and operative in accordance with a preferred embodiment of the present invention, showing the components and their interconnections required to receive, demodulate and convert the ultrasound signals emitted by the system transmitter, to audible signals to be perceived by the listener as surround sound;

Figs. 8A and 8B illustrate how a surround sound headphone system constructed and operative in accordance with a preferred embodiment of the present invention simulates the phase difference psycho-acoustic effect in order to enable the listener to detect the direction from which a sound emanates;

Figs. 9A and 9B show how a surround sound headphone system constructed and operative in accordance with a preferred embodiment of the present invention simulates how the listener detects the direction from which a sound emanates, and by rotating his head towards the sound origin, equalizes the phase of the sound heard by both ears;

Fig. 10A and Fig. 10B illustrate the timing sequence of the receipt of the sound by the left and right ears of a listener using a surround sound headphone system constructed and

operative in accordance with a preferred embodiment of the present invention, and shows how the timing sequence changes when he rotates his head towards his perception of the sound origin, and equalizes the phase of the sound heard by both his ears;

Fig. 11 illustrates how listeners seated over extensive areas of a room equipped with a surround sound headphone system constructed and operative in accordance with a preferred embodiment of the present invention all have the correct spatial illusion of the surround sound;

Fig. 12 is a schematic block diagram of a headphone-based surround sound system constructed and operative in accordance with another preferred embodiment of the present invention, wherein the ultrasound signal of the embodiments of Figs. 5-11 is used as a reference signal and the audio signals are sent by wired or wireless communication to the headphones; and

Fig. 13 is a schematic block diagram of a headphone-based surround sound system constructed and operative in accordance with yet another preferred embodiment of the present invention, this system being substantially the same as the system illustrated in Fig. 12, except that wherein the system of Fig. 12 is a stand-alone system, the system of Fig. 13 is suitable for packaging as a printed circuit board in a personal computer.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

A preferred embodiment of the present invention is described in the field of surround sound systems. However, it is appreciated that the present invention is readily applicable for use in other applications such as virtual reality systems, computer games, simulator systems, and the like.

Reference is now made to Fig. 1 which is a pictorial representation of a prior art conventional speaker-based surround sound system, as described in the "Background to the Invention", showing the component parts and their mutual location with respect to the listener. The parts shown are a TV receiver or video screen 10, an audio signal source 12, such as a laser disk player or video cassette player, the surround sound amplifier 14, the main speakers, namely the front left speaker 16 and the front right 17, the center speaker 18, the rear left speaker 20, and the rear right speaker 21. In this representation, only the five speakers which provide the directional information are shown. The sub-woofer is understood, and its location is not critical. The listener 22 is shown seated at the "sweet spot", the only area in the room where the surround sound effect is felt realistically.

Figs. 2A and 2B show how a listener 22 seated in front of a prior art speaker-based surround sound system is able to detect the direction from which a sound emanates by discerning the small time difference between receipt of the sound by the ear closer to the origin, and by that further from the origin. In Fig. 2A, a sound wave 30 coming from the right front speaker 17 is shown impinging first on the listener's right ear 32. In Fig. 2B, the sound is shown hitting his left ear 34 a short while later, typically 0.3 msec for a signal emanating 30° off axis.

Figs. 3A and 3B are illustrations of the method by which a listener 22 seated in front of a prior art speaker-based surround sound system detects the direction from which a sound emanates, and by rotating his head towards the sound origin, equalizes the phase of the sound heard by both ears.

In Fig. 3A, a sound wave 30 coming from the right front speaker 17 is shown impinging on the listener's ears, with a small time delay between the moment of impingement on the left ear as compared with the right ear. In Fig. 3B, the listener 22 has turned his head in the direction of the sound origin, and is able to detect this direction by mentally discerning when the sound is received by both ears at the same time.

Fig. 4A shows a quantitative depiction of the timing sequences for Figs. 2A and 2B, for the arrival of the sound at the left and right ears of a listener seated in front of a prior art surround sound system. The horizontal axis represents the time elapsed during the propagation of the sound waves. Fig. 4B shows the same timing sequences for the situation depicted in Figs. 3A and 3B, where the listener turns his head towards the sound source.

In Fig. 4A, the sound wave is depicted leaving the speaker 17 at time t_o and arriving at the listener's right ear after a time $t_o + DR/V$, where V is the velocity of the sound, and DR is the distance from the speaker to the right ear 32. The sound arrives at his left ear only after a time $t_o + DL/V$, where $DL > DR$. The listener's brain discerns this slight delay to locate the origin of the sound.

In Fig. 4B, the listener is shown after rotating his head towards the sound origin. The timing sequence shows how the sound wave leaves the speaker 17 at time t_1 and arrives at both of the listener's ears after a time $t_1 + DR/V$, which is identical to $t_1 + DL/V$, since the distance from the speaker to the two ears is equal.

A pictorial representation of a surround sound headphone system, constructed and operative in accordance with a preferred embodiment of the present invention, is shown in Fig. 5. It is seen that the five speakers shown in the conventional prior art system of Fig. 1

have been eliminated. In their place are three small-size components, which comprise the basic components of the headphone surround sound system. These components are a surround sound encoder 24, an ultrasound transducer 26, and a set of surround sound headphones 28.

The surround sound encoder 24 is provided with an input signal from the audio signal source 12 - a laser disk player, a VCR , or any other stereo source. The unit can be connected to a surround sound amplifier 14, such as an external Dolby processor, or it can be fitted with its own internal surround processor. The encoder 24 processes the five conventional separated surround sound channels. The modified signal is then modulated, by AM or FM for example, and amplified to bring it to a sufficient level for transmission. The simulation of different sound sources is made by using four different carrier frequencies on one transmitted ultrasound beam. Two are used to simulate the front sound sources and two for the rear sources.

It is appreciated that even though the described embodiment of this invention is constructed and operative to handle signals coded according to the Dolby recording standard it can easily be adapted to any other 3-D sound recording standard.

The modulated and amplified signal is fed to the ultrasound transducer 26, mounted on top of the TV receiver, and transmitted into the listening room in the form of coded ultrasound waves containing the surround sound signals.

It is appreciated that even though the described embodiment of this invention is constructed and operative to convey all of the audio information by one transmitter, it can easily be adapted to transmit via several transmitters such as one for rear channels and one for front channels.

The surround sound headphones 28 worn by the listener contain two special microphones mounted on each ear-piece, which receive the ultrasound signals transmitted from on top of the TV monitor. Four decoders convert the signal into audio surround sound, which is then amplified and reproduced by the headphones' speakers. Each ear-piece is sensitive to two frequencies - one front and one rear.

The propagation effects of the above described system are now explained. Since ultrasound is a normal sound wave but of super-audible frequency, it propagates through air in exactly the same manner as any other sound wave. It is therefore the specific use of an ultrasound reference signal sent from the transmitter to the listener's head, which enables the surround sound effect produced by the present invention to behave exactly like the audio sound produced by a conventional free space surround sound system. (In the embodiment of

Fig. 5, the ultrasound signal is not only used as the reference signal but also as the carrier signal for the audio information. In another preferred embodiment of the present invention, described hereinbelow with reference to Figs. 12 and 13, the ultrasound signal acts only as the reference signal and the audio information is transmitted separately by wired or wireless communication.)

In particular, all the parameters affecting normal hearing are applicable to ultrasound with respect to the five psycho-acoustic effects mentioned above:

1. The velocity of the ultrasound carrier generates an accurate phase difference between the listener's two ears.
2. The level of the ultrasound carrier causes the correct transduced sound volume differences between the two ears.
3. No special consideration need be given to measuring head movements. The ultrasound is affected by head movements exactly like audible sound signals.
4. The Doppler effect changes the pitch with head rotation in exactly the same way as if real speakers were being used.
5. Due to the location of the ultrasonic receivers on either side of the headphone arms, the face blockage effect is retained.

A further advantage of the use of ultrasound is that, unlike RF, the environment does not interfere with the transmission, giving rise to a noisy signal, nor does the transmission cause interference to the environment.

Fig. 6 shows a schematic block diagram of the encoder unit. This unit modifies the signals from each of the five conventional surround sound input channels 40 - front left, front right, center, rear left and rear right - by means of delay lines 42, operative on the signals according to their source channel and their destination channel. The resulting signal information is routed into four output channels - front left, front right, rear left and rear right - which are, for example, AM or FM modulated 44 onto four different carrier frequencies using a built-in local oscillator, and inputted to a mixer 46, whose output 48 is amplified for feeding to the ultrasound transducer.

The five different input channels are processed and connected in the following manner. The center channel signal is fed directly to the C_{FL} and C_{FR} modulators for transmission by the two front channel carriers - C_{FL} and C_{FR}. The front right channel signal is fed in parallel to two channels - directly to the C_{FR} channel modulator, and to the C_{FL} modulator via a 0.3

msec. delay line (calculated for a sound source located 30° off center). The front left channel, in a manner similar to the right channel, is fed directly to the C_{FL} channel modulator, and with a 0.3 msec. delay to the C_{FR} modulator. The rear right channel signal is connected directly to the C_{RR} modulator, and via a 0.3 msec delay line to C_{RL}. The rear left channel signal is connected directly to the C_{RL} modulator, and via a 0.3 msec delay line to C_{RR}.

In order to see how this method of encoding produces effective surround sound, it is necessary to understand how the decoding process is executed in the surround sound headphones. The construction of these headphones is shown in Fig. 7.

The headphones are based on standard Hi-Fi headphones equipped with additional electronic components, as follows: two ultrasound microphones 50 and 52, four filters 53, 54, 55 and 56, four demodulators 57, 58, 59 and 60, a pair of amplifiers 61 and 62. These amplifiers feed the speakers 63 and 64 of the headphones. The two ultrasound microphones 50, 52, are located one on each ear-piece, on either side of the earphone bridge 65, and act as receivers for the transmitted ultrasound signals. The signals from each of these microphones are filtered and demodulated to extract the two channels, front and rear, associated with each ear. The resulting signals are amplified and fed to each ear-piece's speaker, which transduce them to human audible signals.

Each microphone is connected to both ear-pieces as follows. The front carrier is connected directly to the ear-piece on the side on which the microphone is mounted, and the rear carrier to the opposite ear-piece. Specifically, for the front channels, the right microphone transmits C_{FR} to the right ear and the left microphone transmits C_{FL} to the left ear. For the rear channels, the connections are crossed such that the right microphone transmits C_{RL} to the left ear and the left microphone transmits C_{RR} to the right ear. Using this crossed-connection, any sound source in any direction can be simulated using only one ultrasonic transmission. In particular, rear sound sources are correctly simulated using one transmitter located in the front.

Figs. 8A and 8B illustrate how a surround sound headphone system constructed and operative in accordance with a preferred embodiment of the present invention simulates the phase difference psycho-acoustic effect, enabling the listener 22 to detect the direction from which a sound seems to emanate. In Fig. 8A, two front channel signals C_{FR} and C_{FL} are sent out by the transmitter 26, but with a slight time delay between them. The C_{FL} signal is delayed by about 0.3 msec comparing to C_{FR}. Because of the direct pickup and connection in the earphones, the listener 22 hears the sound first in his right ear 32, and only 0.3 millisecond

later, as shown in Fig. 8B, in his left ear 34. It seems to the listener as if a virtual speaker 36 is located on his right side at about 30°.

Figs. 9A and 9B demonstrate how the surround sound headphone system enables the listener to detect the direction from which a sound emanates by rotating his head towards the sound origin in order to equalize the phase of the sound heard by both ears. The figure nomenclature is the same as in Figs. 8A and 8B. If the listener rotates his head to the right, the delay between the signals C_{FL} and C_{FR} decrease until his head is turned 30° to the right. At this point, the delay is zero and the listener has the illusion of looking directly towards the origin of the sound, as illustrated in Fig. 9B.

Figs. 10A shows a quantitative depiction of the timing sequences for Figs. 8A and 8B, for the arrival of the sound at the left and right ears of a listener using a surround sound headphone system. The horizontal axis represents the time elapsed during the propagation of the sound signals. Fig. 10B shows the same timing sequences for the situation depicted in Figs. 9A and 9B, where the listener turns his head towards the sound source.

In Fig. 10A, the front right signal C_{FR} leaves the transmitter 26, at time t_r and arrives at the listener's right ear after a time $t_r + DR/V$, where V is the velocity of the sound, and DR is the distance from the transmitter to the right ear 32. The front left signal C_{FL} leaves the transmitter 26, at time t_l and arrives at the listener's left ear after a time $t_l + DL/V$. Since DR = DL when the listener is looking forward, the sound arrives at his left ear a time $t_l - t_r$ later than at his right ear, and the listener's brain discerns this slight delay to locate the origin of the sound as if it were to the right of him at about 30°.

In Fig. 10B, the listener is shown after rotating his head towards the sound origin in an attempt to localize its direction. The timing sequence shows how, even though they were transmitted a time $t_l - t_r$ apart, the C_{FR} and C_{FL} signals both seem to arrive at the listener's ears at the same moment, after a time $t_r + DR/V$, equal to $t_l + DL/V$, and give the listener the illusion as if they originated from the direction towards which he turned his head, namely his front right hand side at about 30°.

The reason for the crossed connection for the rear channels in the headphones is now clear. If a real sound source is located in front of the listener, by turning his head to the right for example, his right ear moves further from the source, while his left ear moves closer to it. If on the other hand, the source is located behind him, the effect is opposite, in that by turning his head to the right, for example, his right ear moves closer to the source, while his left ear moves further from it. Thus, sources located behind the listener behave as if they were left-to-

right reversed in comparison to those in front of him. The headphones implement this effect by crossing over the rear connections as shown in Fig. 7.

Several listeners 70, 71, 72, are shown in Fig. 11, sitting in a room equipped with the headphone surround sound transmission system 73. So long as they each have a headphone set, they all have the illusion of complete surround sound, as if a "center speaker" were located in the direction of the TV receiver, and four additional speakers located around each of them in perfect locations. The front virtual speakers are located 30° left and 30° right of the TV set, and the rear speakers, 30° rear left and 30° rear right. In this respect, there are

A preferred embodiment of the present invention includes a headphone surround sound system having many advantages comparing to prior art speaker-based surround sound systems. These advantages are summarized as follows:

1. Surround headphones are considerably cheaper, since :
   a There is no need to cover the room with acoustic absorbing and isolating materials.
   b The need for expensive, space consuming speakers is eliminated.
   c Expensive high power amplifiers are not needed.
2. In most cases, surround headphones provide the listener with improved sound quality and better immersion, since:
   a. The acoustic environment is perfect, since there are no unwanted echoes or external noises.
   b. Because of the low power levels involved, headphones have a considerably lower distortion level than speakers in the same quality class.
   c. Since headphones are very close to the listener's ear, they require only a low power amplifier to drive them, and these too have a considerably lower distortion level than high power amplifiers.
   d. In standard home theater rooms, only a small listening area in the middle of the room, called the "sweet point", is optimum for experiencing the surround sound effect fully. Using surround sound headphones, this area is much more extensive.
3. Headphones are more convenient to use, since:
   a. Every room is suitable for watching surround sound movies, and there is no need to dedicate a special room to this purpose.

b. There is no need to extensively wire the listening room.

c. The listener can use high volume sound reproduction without bothering others.

Reference is now made to Fig. 12 which is a schematic block diagram of a headphone-based surround sound system constructed and operative in accordance with another preferred embodiment of the present invention. In the system of Fig. 12, the ultrasound signal of the embodiments of Figs. 5-11 is used as a reference signal and the audio signals are sent by wired or wireless communication to the headphones. Accordingly, only the audio processing portion of the system is illustrated and described with reference to Fig. 12, the ultrasound reference signal being as described hereinabove with reference to Figs. 5-11.

An analog-to-digital converter 102 receives analog audio signals, such as from 5 x PreAmp Surround or any other kind of analog stereo input. The audio signals contain, for example, the information corresponding to front right, front left, center, rear right, rear left, as described hereinabove. The signals are then sent for processing, preferably via a data controller 104, to a signal processor 106. Signal processor 106 may be packaged as an FPGA. (Optionally, data controller 104 may receive a digital audio input, such as digital AC-3 input via an AC-3 decoder 114.)

In order to process the signals, ultrasound transducer 26 (Fig. 5) sends an ultrasound reference signal to ultrasound microphones 50 and 52 (Fig. 7). A head angle calculator 120 processes arrival times of the ultrasound reference signal at each ear, so as to measure a phase difference of the reference signal as perceived by one ear in contrast to the other ear, as described hereinabove. In this manner, head angle calculator 120 calculates the azimuthal angular movement α and elevational angular movement β of the head. The angular movements are sent by data controller 104 to signal processor 106 for modulating the audio input in accordance with the phase difference, in order to provide the user with the correctly directed sound, as described hereinabove.

Alternatively, a head sensor 116 may be provided, for example, mounted on surround sound headphones 28 worn by a user, which senses movement of the head of the user. For example, head sensor 116 may sense azimuthal angular movement and elevational angular movement of the head, and send the sensed data to head angle calculator 120 via a head sensor interface 118, such as an amplifier. An input switch 122 may be provided for selecting and switching between the kind of inputs available, ultrasound, or non-ultrasound.

The signal processing may be carried out by any known method, such as, but not necessarily, FIR (finite impulse response). As seen in Fig. 12, during the course of signal

processing, signal processor 106 may cooperate with an input buffer 108 and a memory device 109. Input buffer 108 may be any kind of suitable buffer, such as a fast RAM (20 ns, 5K x 16 bit). Signal processor 106 may comprise a decoder, such as a ProLogic Decoder, if it is required to decode the signals.

Preferably signal processor 106 cooperates with input buffer 108 in the following way. If, for example, an audio input is coming from 0° with respect to the listener (i.e., directly in front of the listener) or if it is desired to artificially mimic an audio input coming from 0°, then signal processor 106 takes the audio input for each ear at the same time from buffer 108. However, if an audio input is coming from 30° with respect to the listener, or if it is desired to artificially mimic an audio input coming from 30°, then signal processor 106 takes the audio input from buffer 108 for one ear, then waits a certain time delay corresponding to the delay that the listener would in real life sense between both ears, and only then takes the input for the other ear from buffer 108.

The processed signals are preferably output to a D-A converter 110 which sends the processed signals to headphones 28 via an LNA 112, or alternatively or additionally to a stereo speaker or subwoofer.

It is important to point out that the embodiment of Fig. 12 is different from the prior art mentioned above in the background, namely, USA Patent Nos. 5,181,248, 5,452,359 and 5,495,534. In the prior art, the angular location of the head is also obtained from relative time-of-arrival measurements of an ultrasonic reference signal emitted by a transmitter located in front of the listener, by means of ultrasonic detectors located in the left and right arms of the headphone set. However, the prior art can only measure angular changes in azimuth corresponding to sideways motion of the head. In contrast, the present invention can measure and respond to any kind of angular motion, including elevation and roll and any combination of angular and linear movement of the head. The prior art cannot measure distance between ears of the listener. This is a particularly important drawback because not every listener has the same size head and so the sound effects are different for each user. In contrast, the present invention does indeed measure the distance between the two ears of the user and modifies the audio input to the two ears accordingly, as described hereinabove. In addition, the prior art does not use an input buffer as does the present invention (input buffer 108) as described hereinabove.

Fig. 13 is a schematic block diagram of a headphone-based surround sound system constructed and operative in accordance with yet another preferred embodiment of the

present invention, this system being substantially the same as the system illustrated in Fig. 12, except that wherein the system of Fig. 12 is a stand-alone system, the system of Fig. 13 is suitable for packaging as a printed circuit board in a personal computer.

It will be appreciated by persons skilled in the art that the present invention is not limited by what has been particularly shown and described hereinabove. Rather the scope of the present invention includes both combinations and subcombinations of the various features described hereinabove as well as variations and further developments thereof which would occur to persons skilled in the art upon reading the foregoing description and which are not in the prior art.

CLAIMS

What is claimed is:

1. A wireless headphone assembly comprising:

at least one ultrasound receiver for receiving at least one ultrasound signal along at least one ultrasound channel; and

at least one transducer for converting each of said at least one ultrasound signal along said at least one ultrasound channel to a human audible signal.

2. The wireless headphone assembly according to claim 1 and wherein said at least one ultrasound receiver comprises two ultrasound receivers, each of which receives an ultrasound signal along two ultrasound channels.

3. The wireless headphone assembly according to claim 2 and wherein said two ultrasound receivers, called a right receiver and a left receiver, provide ultrasound signals to right and left ears of a user, wherein the right receiver provides a front right signal to the right ear and the left receiver provides a front left signal to the left ear, and wherein the right receiver provides a rear left signal to the left ear and the left receiver provides a rear right signal to the right ear.

4. The wireless headphone assembly according to claim 1 and wherein said at least one ultrasound receiver comprises four ultrasound receivers, each of which receives an ultrasound signal along one ultrasound channel.

5. The wireless headphone assembly according to claim 1 and wherein said at least one transducer comprises at least one first transducer which converts said at least one ultrasound signal to at least one modulated electrical signal and at least one second transducer which converts said at least one modulated electrical signal to a human audible signal.

6. The wireless headphone assembly according to claim 5 and wherein said at least one transducer comprises at least one multichannel transducer.

7. The wireless headphone assembly according to claim 1 and also comprising at least one band pass filter associated with each ultrasound channel.

8. The wireless headphone assembly according to claim 1 and also comprising at least one demodulator associated with each ultrasound channel.

9. The wireless headphone assembly according to claim 1 and wherein said at least one first transducer is operative to convert said at least one ultrasound signal to at least one modulated electrical signal. comprises at least two first transducers, each arranged to be located adjacent a different ear of a user.

10. The wireless headphone assembly according to claim 1 and wherein said at least one second transducer comprises at least two second transducers, each providing a human audible output to a different ear of a user.

11. The wireless headphone assembly according to claim 10 and wherein a human audible signal derived from ultrasound signals received at each of said at least two ultrasound receivers is supplied to each ear of a user.

12. The wireless headphone assembly according to claim 11 and wherein:

said at least two ultrasound receivers each receive ultrasound signals along at least two ultrasonic channels;

said at least two second transducers convert ultrasound signals along at least two human audible channels to human audible signals; and

information received along each one of said at least two channels of each of said at least two ultrasound receivers is supplied to each of two different ears of the user along a separate one of said human audible channels.

13. The wireless headphone assembly according to claim 12 and comprising delay lines operative to simulate the acoustic delay occurring between the arrival of sound from a signal source at the two ears of the user.

14. A headphone system providing a simulated multi-source sound environment comprising:

at least one headphone assembly which may be worn by a user, including:

at least one ultrasound receiver for receiving at least one ultrasound signal along at least one ultrasound channel; and

at least one transducer for converting each of said at least one ultrasound signal along said at least one ultrasound channel to a human audible signal;

at least one processor receiving a multi-source signal and modulating an ultrasound carrier along a plurality of channels, in accordance with said multi-source signal, and

at least one transmitter for transmitting said modulated ultrasound carrier to the at least one headphone assembly along said plurality of channels.

15. The headphone system according to claim 14, and wherein the use of ultrasound for transmitting said modulated carrier to said at least one headphone assembly is operative to cause a listener using said headphone assembly to experience psycho-acoustic effects that said listener would experience if the multi-source signal were transmitted in free space as audible sound waves from suitably located sound sources.

16. A headphone system comprising:

a headphone assembly which may be worn by a user; and

two audio receivers, called a right receiver and a left receiver, mounted in said headphone assembly, said receivers providing received audio signals to right and left ears of the user, wherein the right receiver provides a front right signal to the right ear and the left receiver provides a front left signal to the left ear, and wherein the right receiver provides a rear left signal to the left ear and the left receiver provides a rear right signal to the right ear.

17. A method for simulating an artificial sound environment comprising:

converting an audible signal to an ultrasound wave;

receiving said ultrasound wave by means of a wireless headphone assembly, and

converting said ultrasound wave to an audible signal by means of said wireless headphone assembly.

18. A method for simulating an artificial sound environment comprising:

sending an ultrasound reference signal to a headphone assembly worn by a user having two ears, said headphone assembly audibly providing at least one audio signal to each of the ears;

processing arrival times of said ultrasound reference signal at each said ear, so as to measure a phase difference of said signal as perceived by one said ear in contrast to the other ear and to measure a distance between the two ears of the user;

modulating at least two audio signals, at least one signal for each said ear, in accordance with said phase difference; and

sending said at least two audio signals via said headphone assembly to each of the ears.

19. The method according to claim 18 and comprising sending said at least two audio signals and said ultrasound reference signal via an ultrasound carrier.

20. The method according to claim 18 and wherein the step of sending said at least two audio signals comprises sending the signals to said headphone assembly by wired communication.

21. The method according to claim 18 and wherein the step of sending said at least two audio signals comprises sending the signals to said headphone assembly by wireless communication.

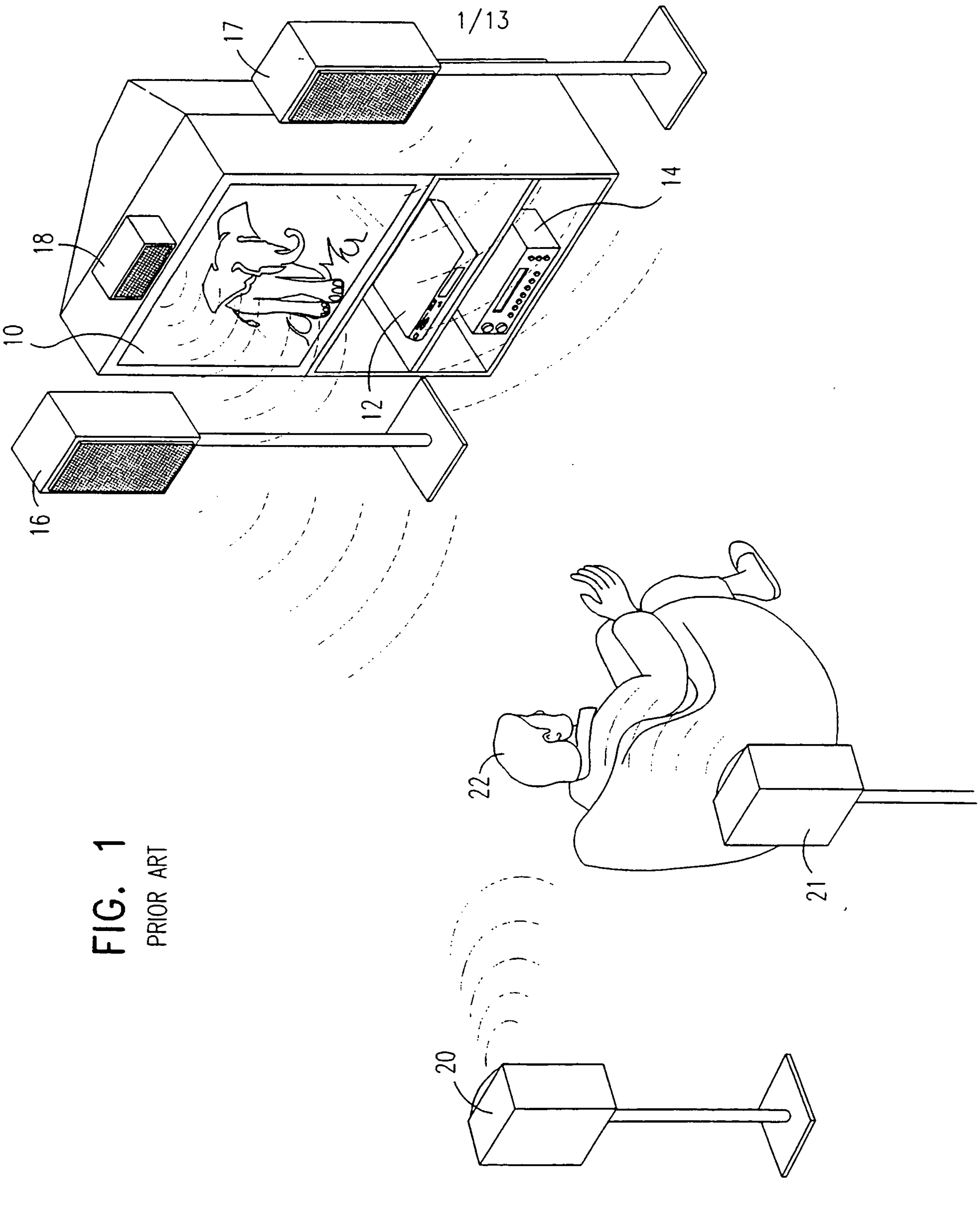


FIG. 1
PRIOR ART

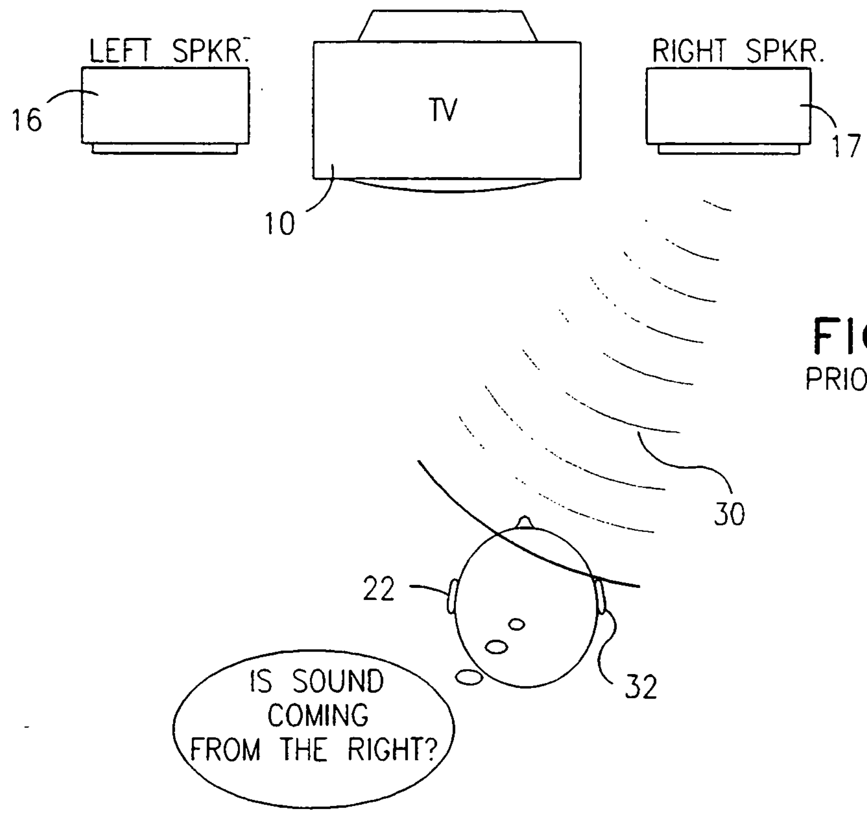


FIG.2A
PRIOR ART

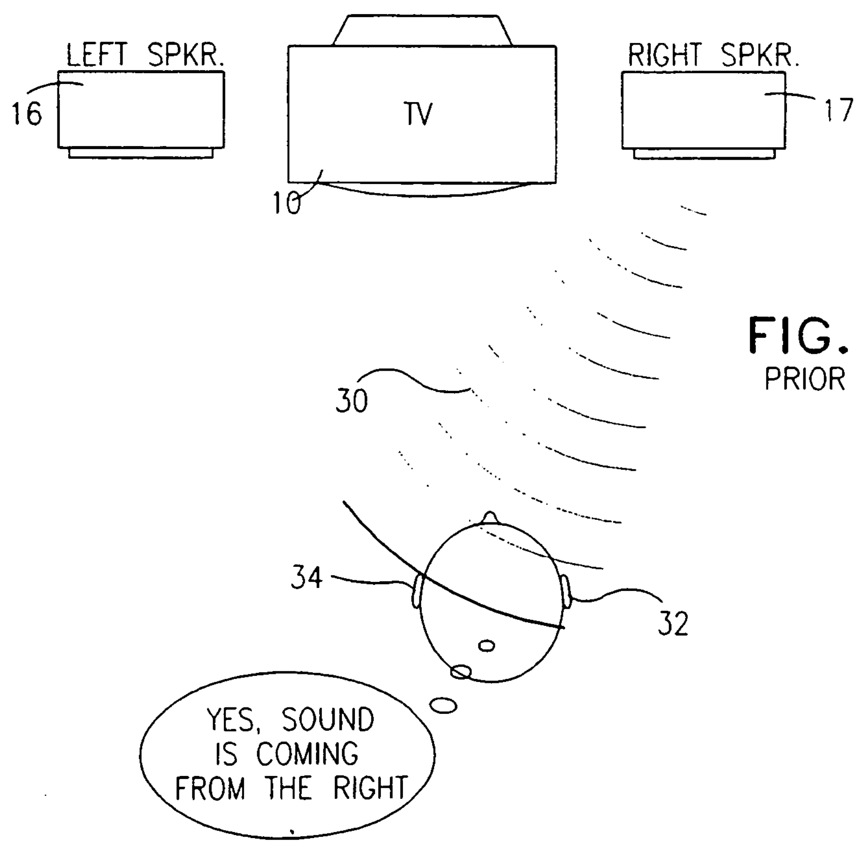


FIG.2B
PRIOR ART

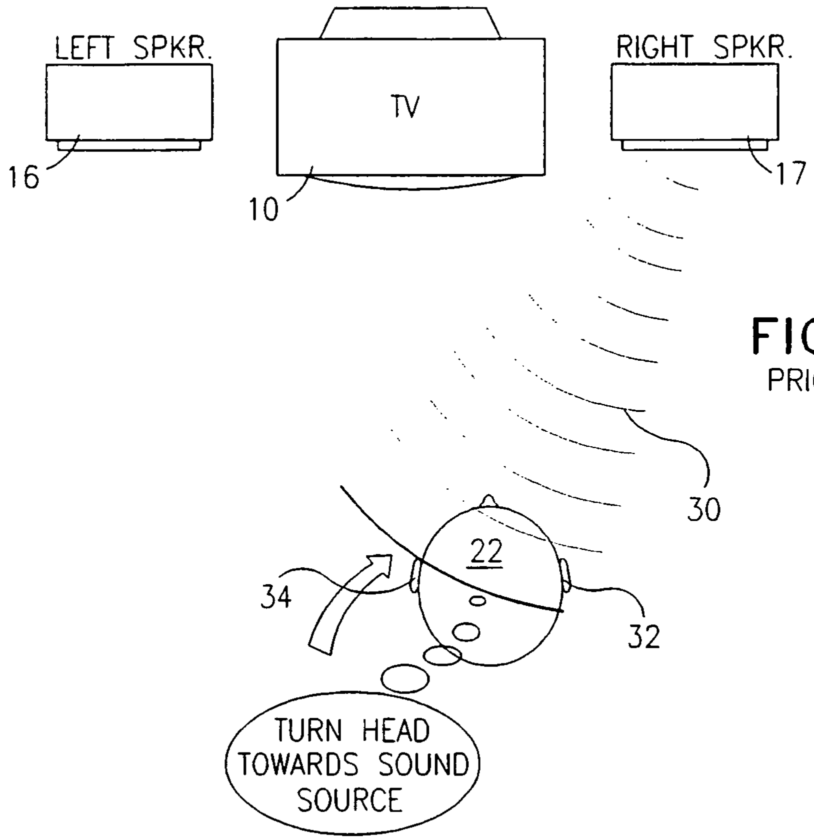


FIG.3A
PRIOR ART

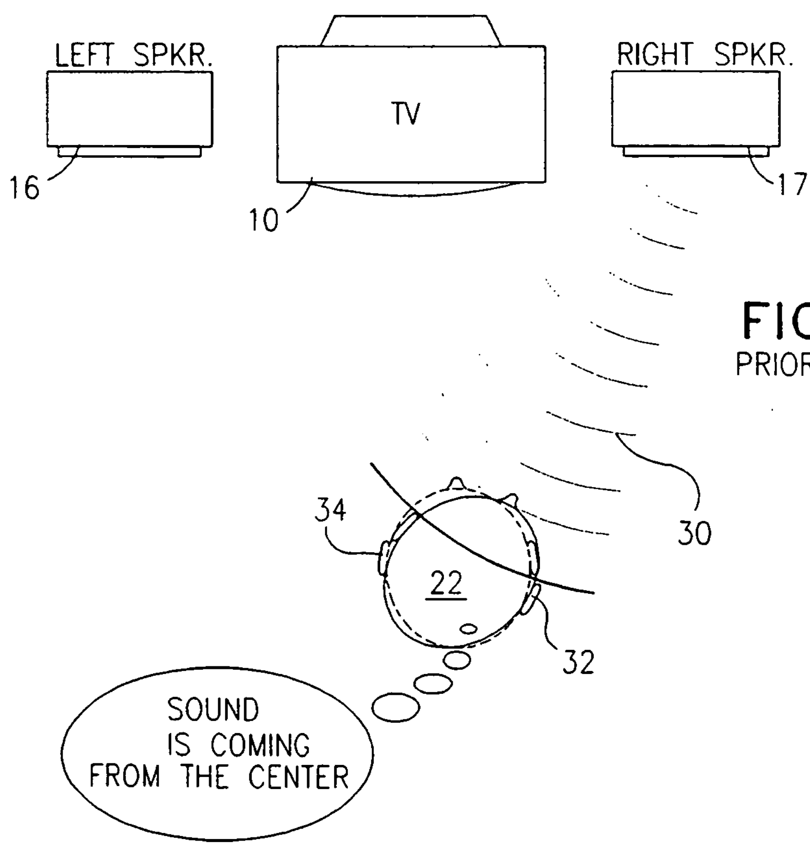


FIG.3B
PRIOR ART

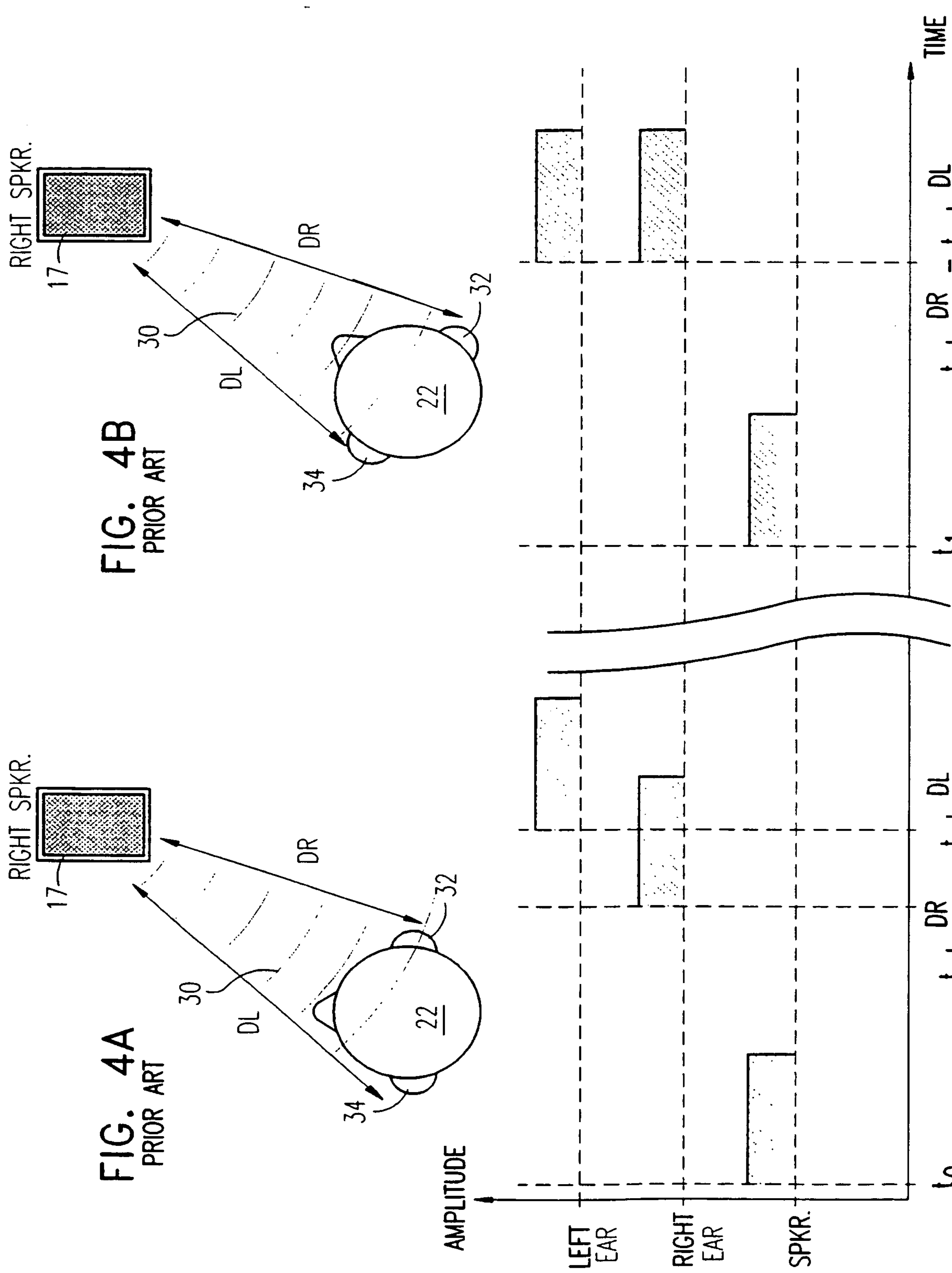


FIG. 4A PRIOR ART

FIG. 4B PRIOR ART

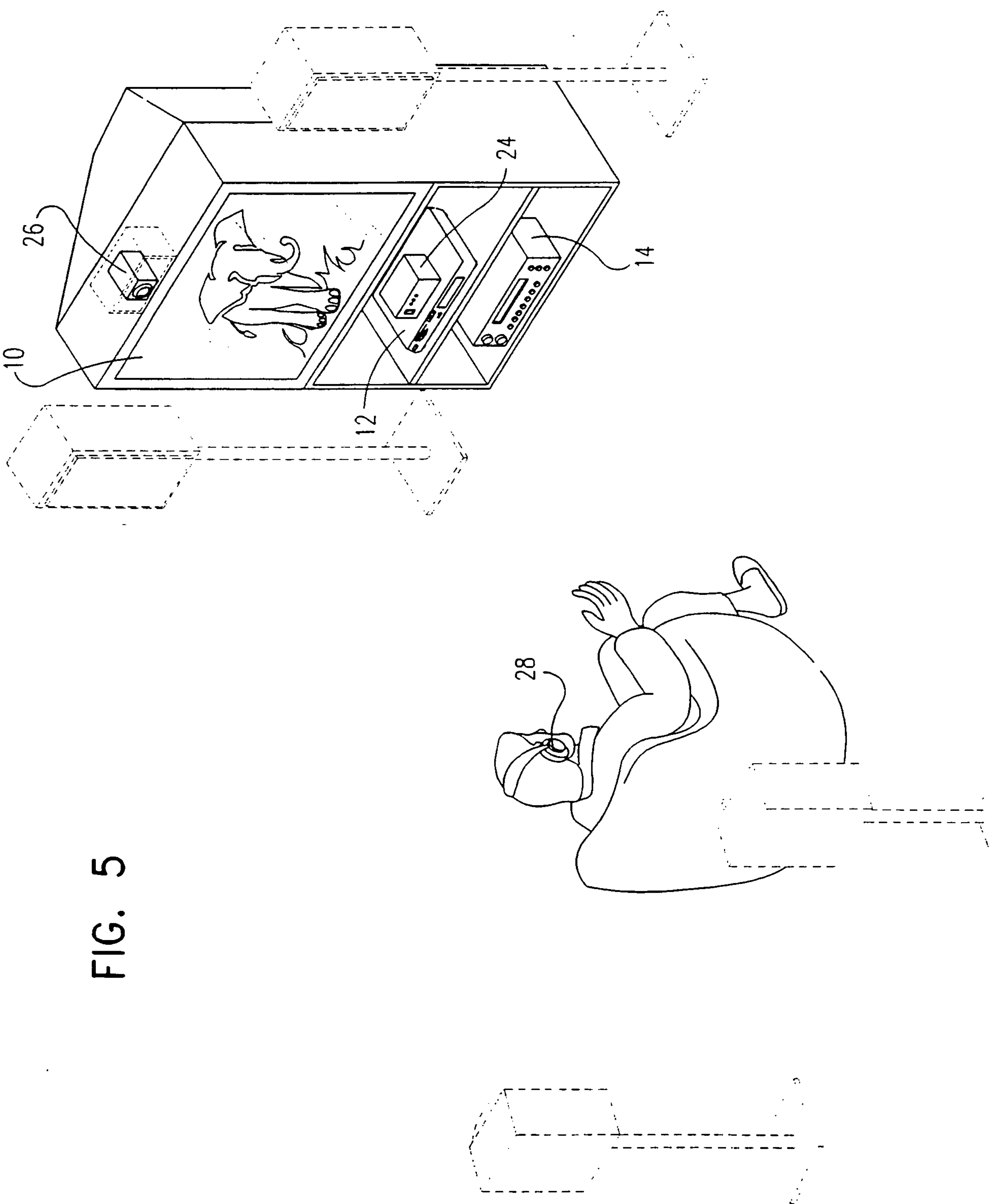


FIG. 5

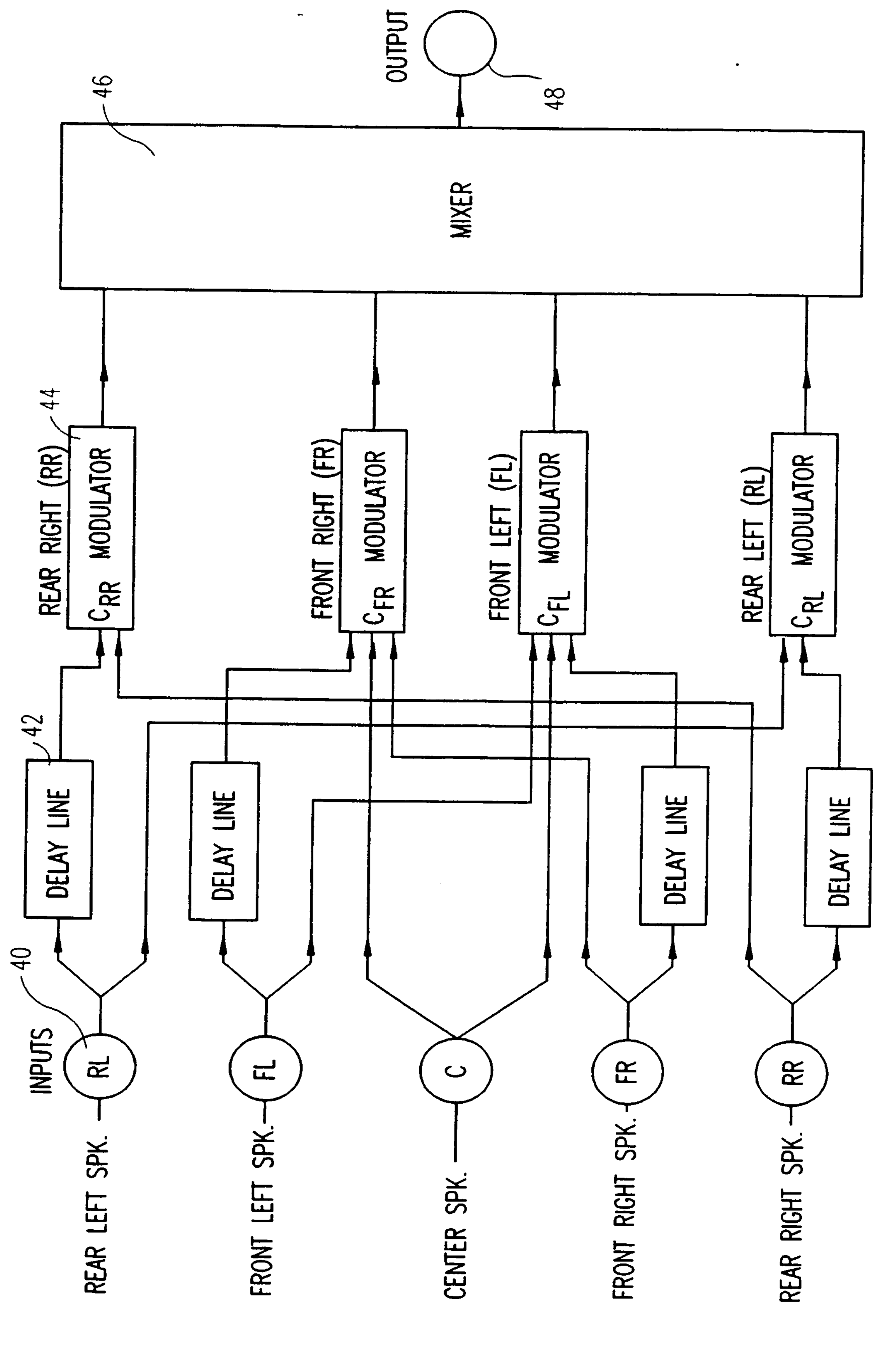

OUTPUT
48
46
MIXER
44
REAR RIGHT (RR)
C_{RR} MODULATOR
FRONT RIGHT (FR)
C_{FR} MODULATOR
FRONT LEFT (FL)
C_{FL} MODULATOR
REAR LEFT (RL)
C_{RL} MODULATOR
42
DELAY LINE
DELAY LINE
DELAY LINE
DELAY LINE
40
INPUTS
RL
FL
C
FR
RR
REAR LEFT SPK.
FRONT LEFT SPK.
CENTER SPK.
FRONT RIGHT SPK.
REAR RIGHT SPK.

FIG. 6

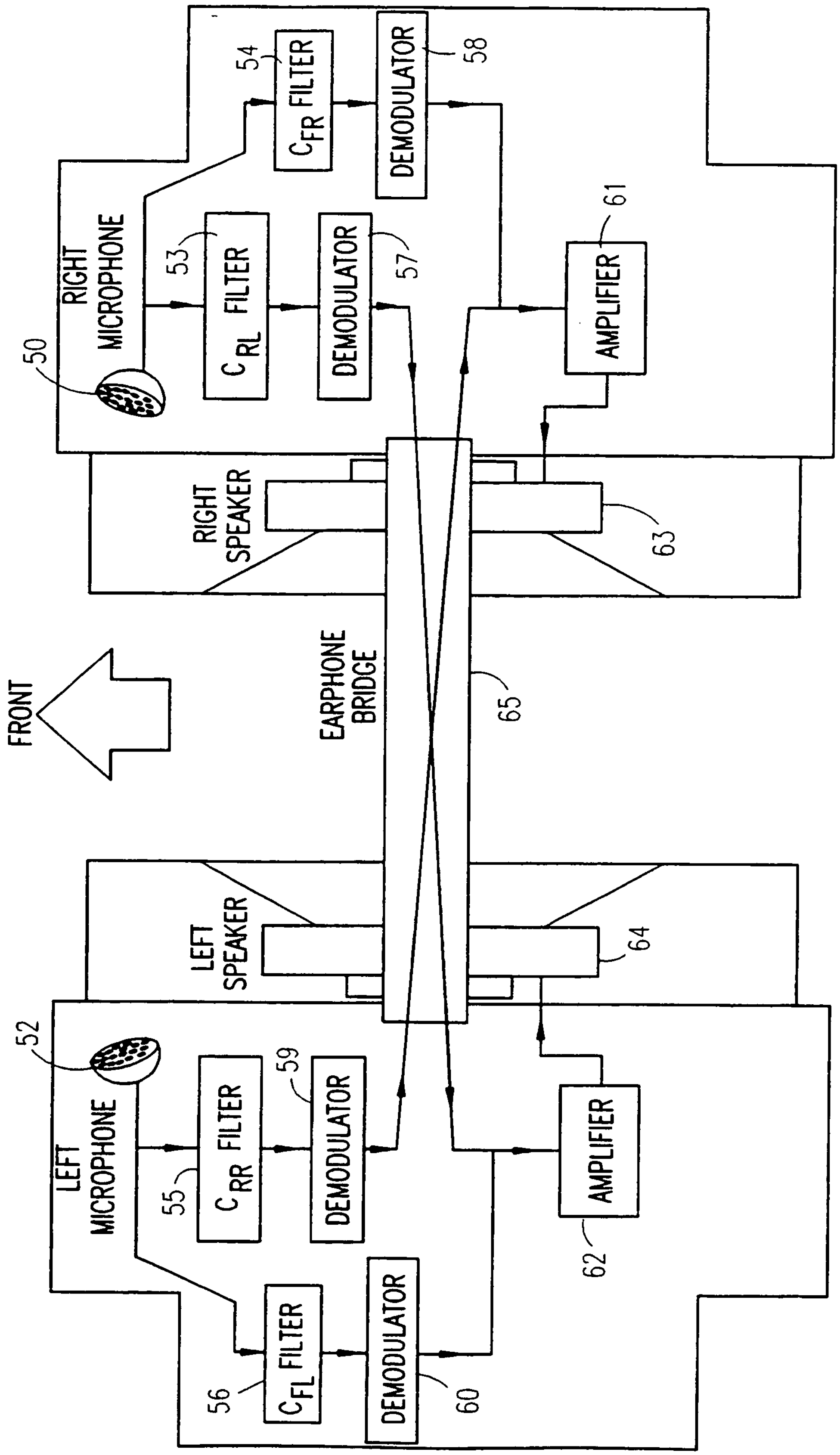

RIGHT MICROPHONE
50
53
C_{RL} FILTER
DEMODULATOR
57
54
C_{FR} FILTER
DEMODULATOR
58
AMPLIFIER
61
RIGHT SPEAKER
63
FRONT
EARPHONE BRIDGE
65
LEFT SPEAKER
64
LEFT MICROPHONE
52
C_{RR} FILTER
55
DEMODULATOR
59
AMPLIFIER
62
C_{FL} FILTER
56
DEMODULATOR
60

FIG.7

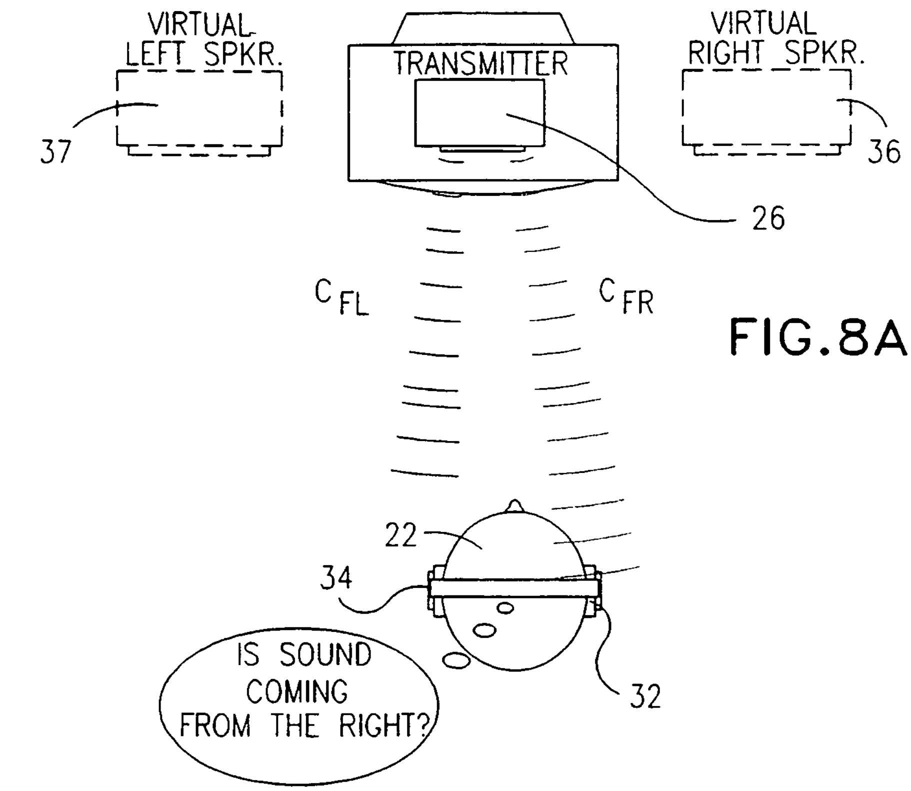

VIRTUAL LEFT SPKR.
TRANSMITTER
VIRTUAL RIGHT SPKR.
37
36
26
C FL
C FR
22
34
32
IS SOUND COMING FROM THE RIGHT?

FIG.8A

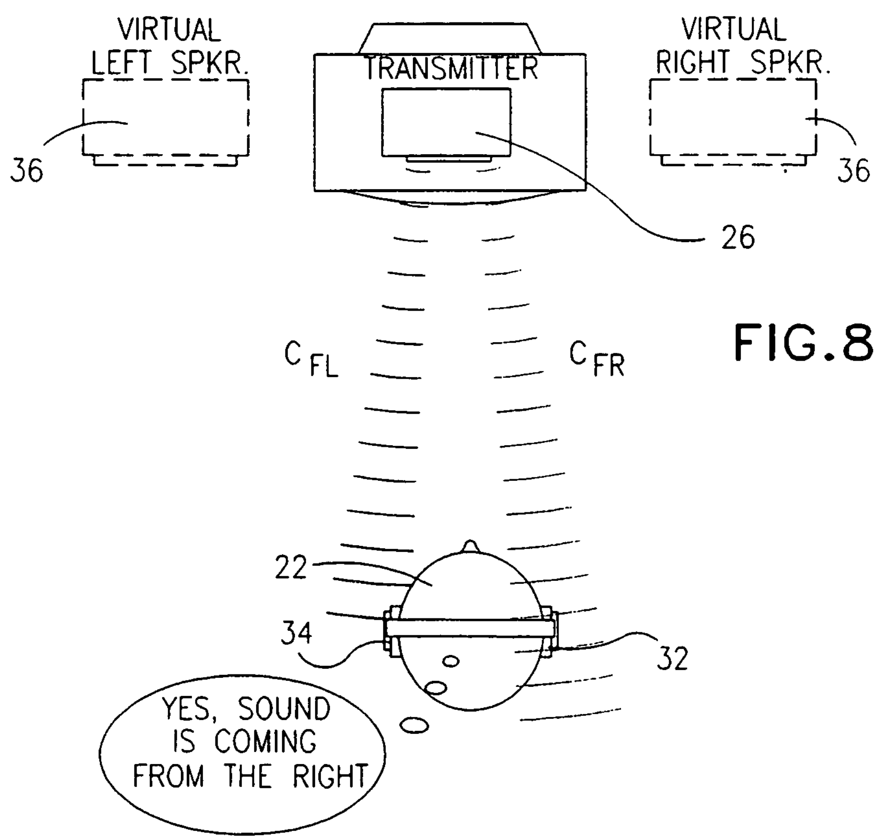

VIRTUAL LEFT SPKR.
TRANSMITTER
VIRTUAL RIGHT SPKR.
36
36
26
C FL
C FR
22
34
32
YES, SOUND IS COMING FROM THE RIGHT

FIG.8B

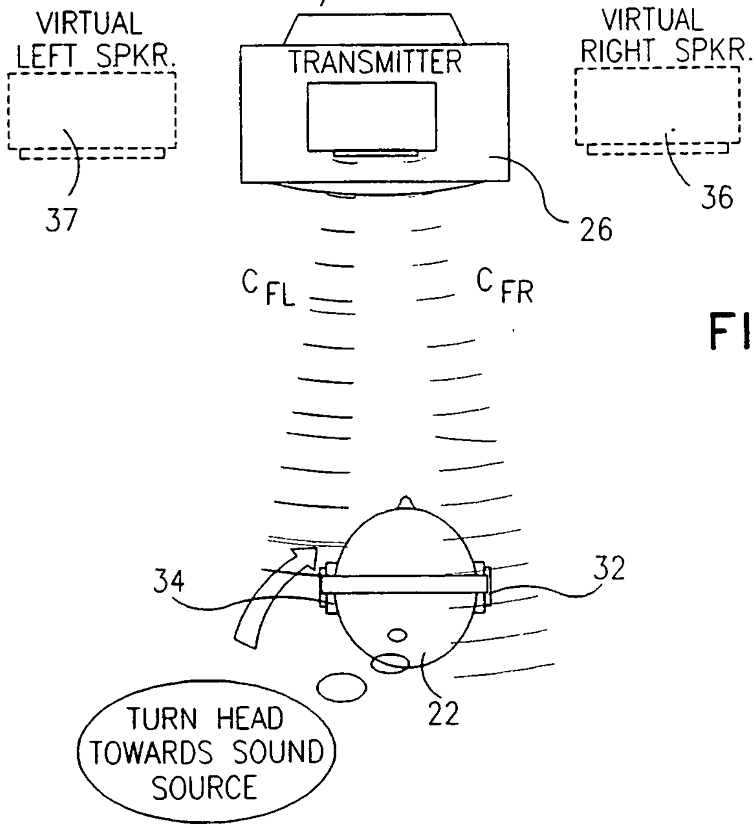

VIRTUAL
LEFT SPKR.
TRANSMITTER
VIRTUAL
RIGHT SPKR.
37
26
36
C FL
C FR
34
32
22
TURN HEAD
TOWARDS SOUND
SOURCE

FIG. 9A

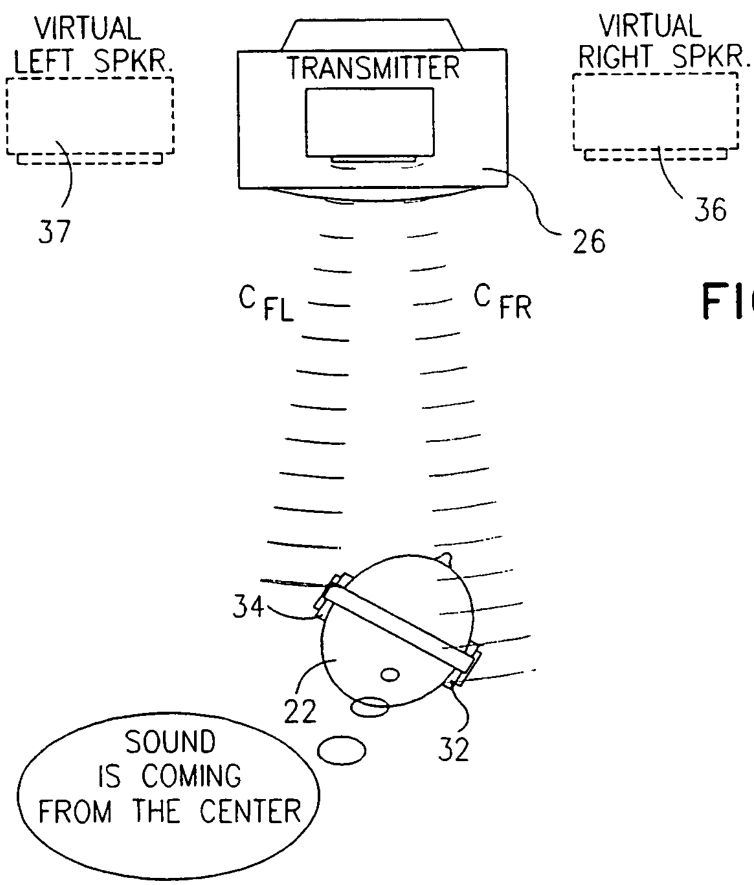

VIRTUAL
LEFT SPKR.
TRANSMITTER
VIRTUAL
RIGHT SPKR.
37
26
36
C FL
C FR
34
22
32
SOUND
IS COMING
FROM THE CENTER

FIG.9B

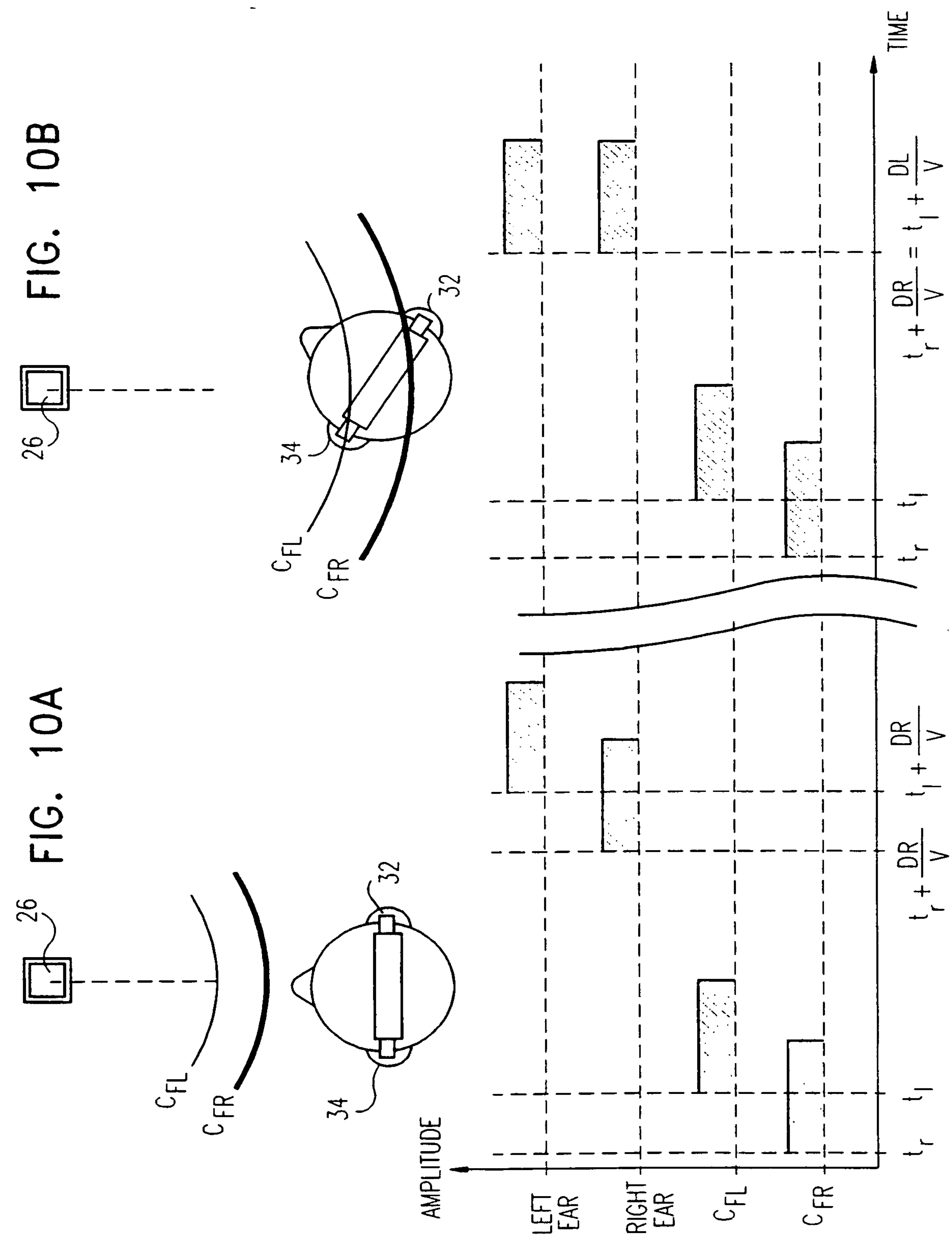


FIG. 10A

FIG. 10B

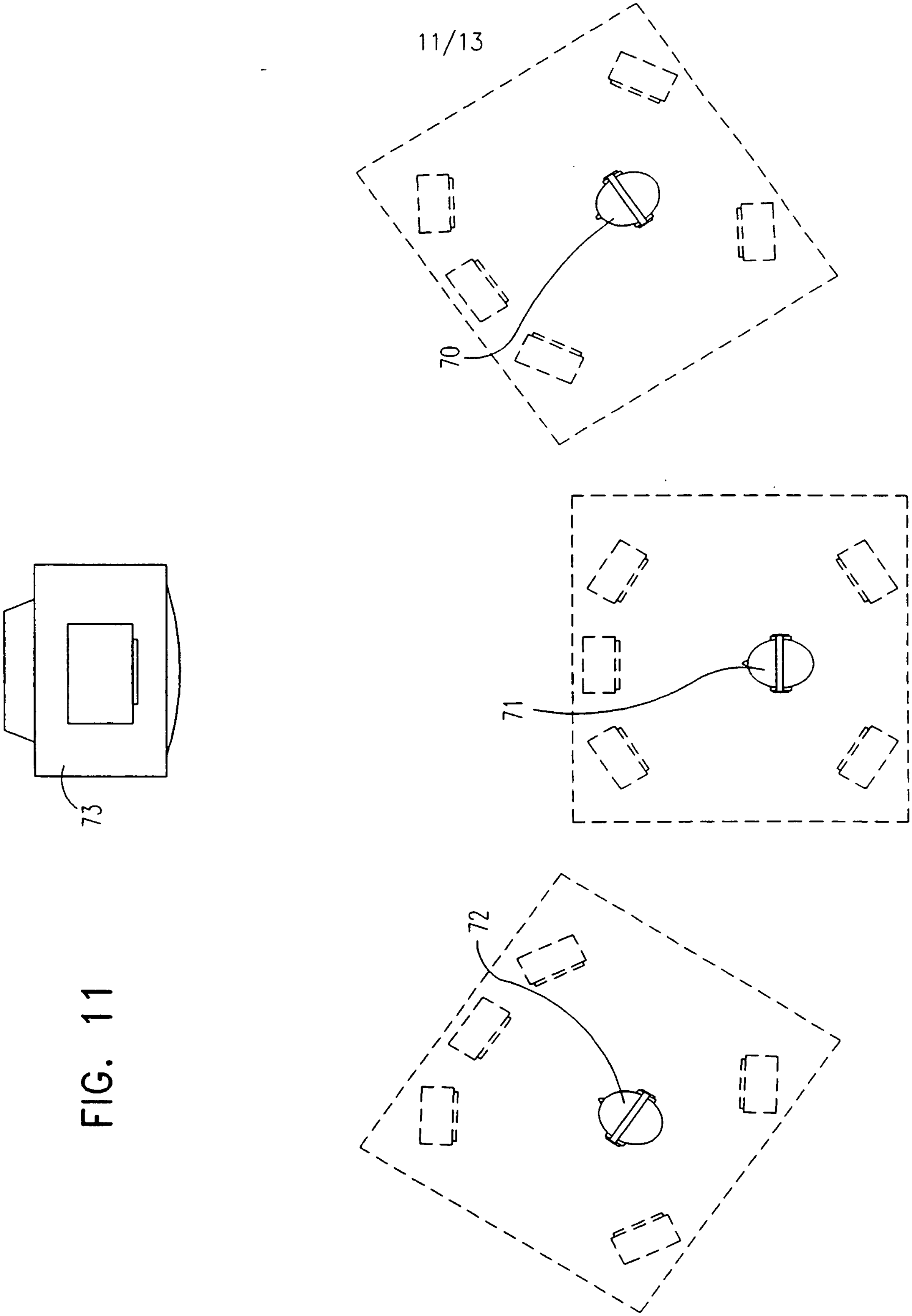


FIG. 11

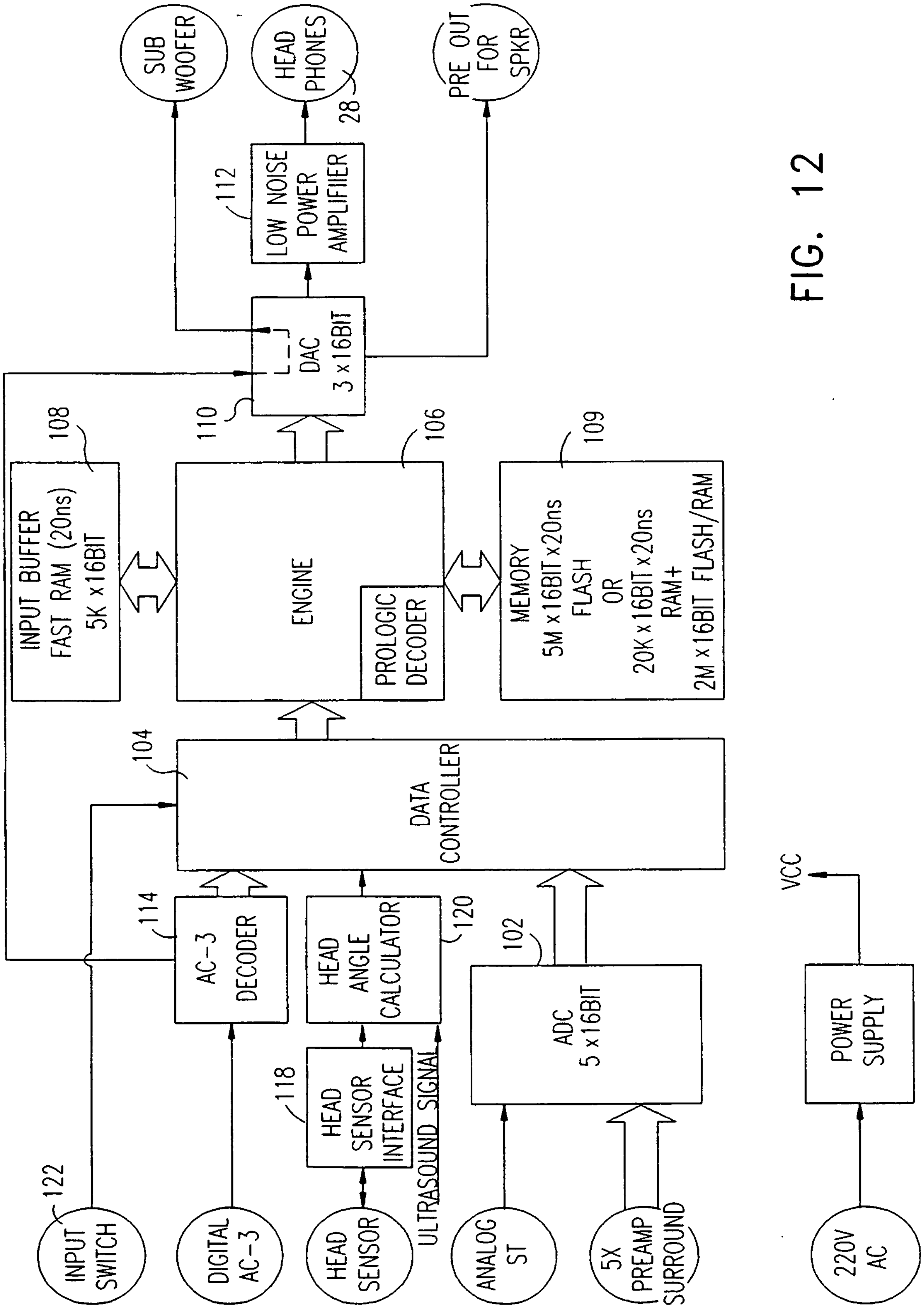

SUB WOOFER
HEAD PHONES
28
PRE OUT FOR SPKR
112
LOW NOISE POWER AMPLIFIIER
DAC 3 x16BIT
110
108
INPUT BUFFER FAST RAM (20ns) 5K x16BIT
106
ENGINE
PROLOGIC DECODER
109
MEMORY 5M x16BIT x20ns FLASH OR 20K x16BIT x20ns RAM+ 2M x16BIT FLASH/RAM
104
DATA CONTROLLER
114
AC-3 DECODER
HEAD ANGLE CALCULATOR
120
102
ADC 5 x16BIT
VCC
POWER SUPPLY
118
HEAD SENSOR INTERFACE
ULTRASOUND SIGNAL
122
INPUT SWITCH
DIGITAL AC-3
HEAD SENSOR
ANALOG ST
5X PREAMP SURROUND
220V AC

FIG. 12

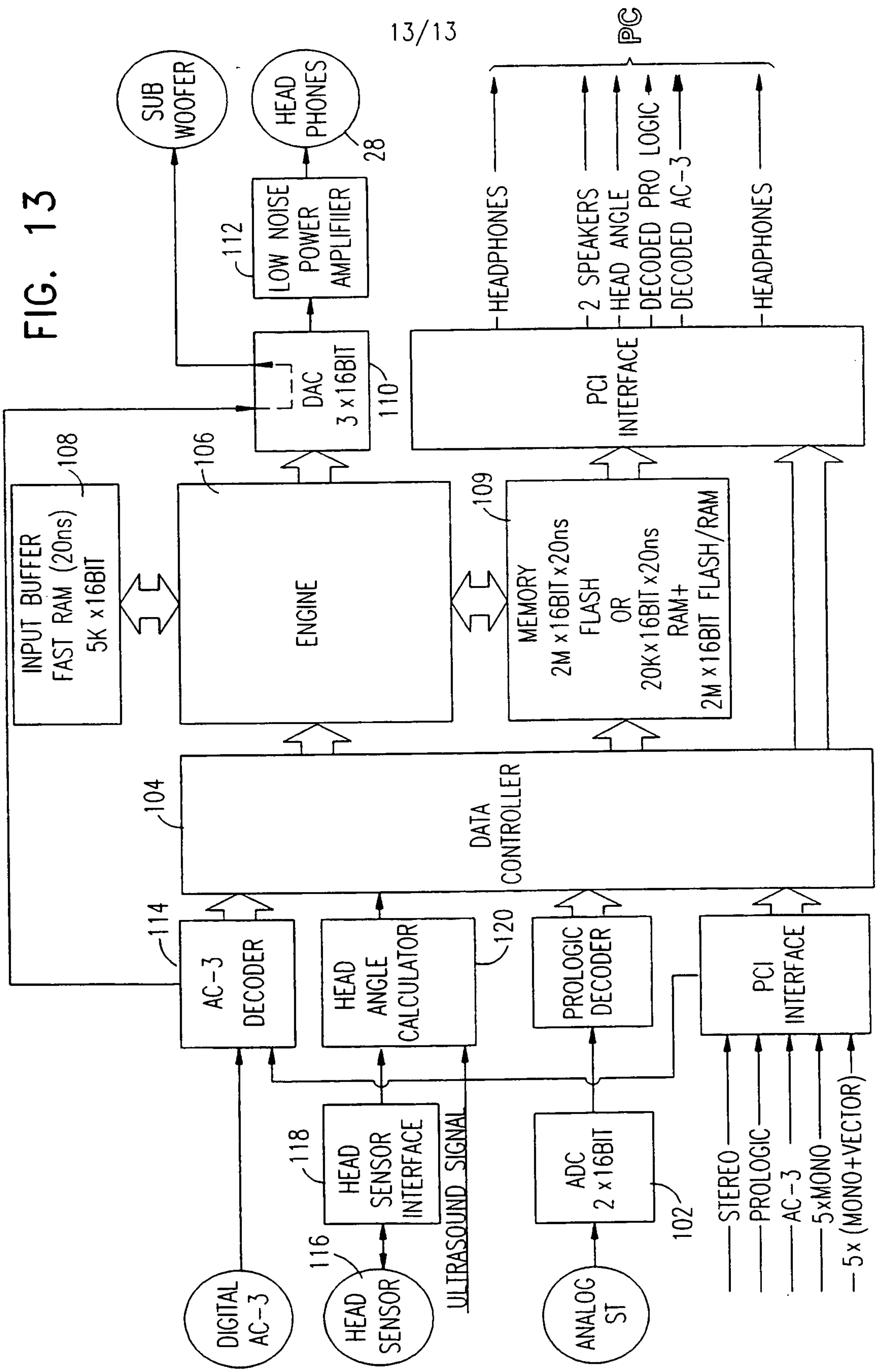

SUB WOOFER
HEAD PHONES
28
LOW NOISE POWER AMPLIFIIER
112
DAC 3 x 16BIT
110
PC
HEADPHONES
2 SPEAKERS
HEAD ANGLE
DECODED PRO LOGIC
DECODED AC-3
HEADPHONES
PCI INTERFACE
INPUT BUFFER FAST RAM (20ns) 5K x 16BIT
108
ENGINE
106
MEMORY 2M x 16BIT x 20ns FLASH OR 20K x 16BIT x 20ns RAM+ 2M x 16BIT FLASH/RAM
109
DATA CONTROLLER
104
AC-3 DECODER
114
HEAD ANGLE CALCULATOR
120
PROLOGIC DECODER
PCI INTERFACE
HEAD SENSOR INTERFACE
118
ULTRASOUND SIGNAL
ADC 2 x 16BIT
102
STEREO
PROLOGIC
AC-3
5xMONO
5x (MONO+VECTOR)
DIGITAL AC-3
HEAD SENSOR
116
ANALOG ST

FIG. 13

CLAIMS

1. A wireless headphone assembly, comprising:

at least one ultrasound receiver for receiving at least one ultrasound signal along at least one ultrasound channel;

at least one transducer for converting each of said at least one ultrasound signal along said at least one ultrasound channel to a human audible signal, and wherein said two ultrasound receivers, called a right receiver and a left receiver, provide ultrasound signals to right and left ears of a user, wherein the right receiver provides a front right signal to the right ear and the left receiver provides a front left signal to the left ear, and wherein the right receiver provides a rear left signal to the left ear and the left receiver provides a rear right signal to the right ear.

2. The wireless headphone assembly according to claim 1 and wherein said at least one ultrasound receiver comprises two ultrasound receivers, each of which receives an ultrasound signal along two ultrasound channels.

3. The wireless headphone assembly according to claim 1 and wherein said at least one ultrasound receiver comprises four ultrasound receivers, each of which receives an ultrasound signal along one ultrasound channel.

4. The wireless headphone assembly according to claim 1 and wherein said at least one first transducer is operative to convert said at least one ultrasound signal to at least one modulated electrical signal, comprises at least two first transducers, each arranged to be located adjacent a different ear of a user.

5. The wireless headphone assembly according to claim 1 and wherein said at least one transducer comprises at least two second transducers, each providing a human audible output to a different ear of a user.

6. The wireless headphone assembly according to claim 5 and wherein a human audible signal derived from ultrasound signals received at each of said at least two ultrasound receivers is supplied to each ear of a user.

7. The wireless headphone assembly according to claim 6 and wherein:

said at least two ultrasound receivers each receive ultrasound signals along at least two ultrasonic channels;

said at least two second transducers convert ultrasound signals along at least two human audible channels to human audible signals; and

information received along each one of said at least two channels of each of said at least two ultrasound receivers is supplied to each of two different ears of the user along a separate one of said human audible channels.

8. The wireless headphone assembly according to claim 7 and comprising delay lines operative to simulate the acoustic delay occurring between the arrival of sound from a signal source at the two ears of the user.

9. A headphone system providing a simulated multi-source sound environment, comprising:

at least one headphone assembly which may be worn by a user, including:

at least two ultrasound receivers for receiving at least one ultrasound signal along at least two ultrasound channels; and

at least one transducer for converting each of said at least one ultrasound signal along said at least two ultrasound channels to a human audible signal;

at least one processor receiving a multi-source signal and modulating an ultrasound carrier along a plurality of channels, in accordance with said multi-source signal; and

at least one transmitter for transmitting said modulated ultrasound carrier to the at least one headphone assembly along said plurality of channels, wherein the use of ultrasound for transmitting said modulated carrier to said at least one headphone assembly is operative to cause a listener using said headphone assembly to experience surround sound effects that said listener would experience if the multi-source signal were transmitted in free space as audible sound waves from suitably located sound sources.

10. A headphone system, comprising:

a headphone assembly which may be worn by a user; and

two audio receivers, called a right receiver and a left receiver, mounted in said headphone assembly, said receivers providing received audio signals to right and left ears of the user, wherein the right receiver provides a front right signal to the

right ear and the left receiver provides a front left signal to the left ear, and wherein the right receiver provides a rear left signal to the left ear and the left receiver provides a rear right signal to the right ear.

11. A method for simulating an artificial sound environment, comprising:

sending an ultrasound reference signal to a headphone assembly worn by a user having two ears, said headphone assembly audibly providing at least one audio signal to each of the ears;

processing arrival times of said ultrasound reference signal at each said ear, so as to measure a phase difference of said signal as perceived by one said ear in contrast to the other ear and to measure a distance between the two ears of the user;

modulating at least two audio signals, at least one signal for each said ear, in accordance with said measured difference; and

sending said at least two audio signals via said headphone assembly to each of the ears.

12. The method according to claim 11 and comprising sending said at least two audio signals and said ultrasound reference signal via an ultrasound carrier.

13. The method according to claim 11 and wherein the step of sending said at least two audio signals comprises sending the signals to said headphone assembly by wired communication.

14. The method according to claim 11 and wherein the step of sending said at least two audio signals comprises sending the signals to said headphone assembly by wireless communication.

15. A method for simulating an artificial sound environment, comprising:

providing a headphone system as claimed in claim 10;

measuring the distance between the ears of a user wearing said headphone assembly, and

producing an artificial sound environment in consideration of said measured distance and in response to any linear and/or angular motion of the user's head.